SOME STUDIES ON SLOWLY AVAILABLE

NITROGEN SOURCES IN HAWAIIAN SOILS

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SOME STUDIES ON SLOWLY AVAILABLE NITROGEN SOURCES IN HAWAIIAN SOILS

INTRODUCTION

Most of the nitrogen fertilizers used by farmers are applied as ammonium (NH_4)[1/] or nitrate (NO_3) salts, anhydrous and aqueous ammonia and urea. In the ammonium form, nitrogen is held in the soil exchange complex and generally is not lost by leaching or volatization. In most soils, however, ammonium nitrogen is quickly converted to nitrate nitrogen by the soil microbial population. The nitrate nitrogen is soluble in water and is subjected to loss by leaching.

Several methods have been used to increase the efficiency of nitrogen fertilizers. These include the use of slowly available N sources, such as natural organics, slightly water-soluble N fertilizers and coated materials. N fertilizers with controlled availability should supply N continuously over an extended period, thus avoiding the need for repeat applications as is necessary with water-soluble forms. They also should minimize luxury consumption of N which upsets nutrient balance, as well as reduce N losses by leaching, decrease gaseous losses of nitrogen and reduce the hazard of injury from over application.

A survey of literature reveals that there is no shortage of information on the nature of slowly available nitrogen sources, the factors

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[1/] Ionic forms are used without indication of charge in this thesis, except where charge indication is essential to the meaning.

affecting the mineralization of these compounds in soils, and their effectiveness as fertilizers. However, such information is virtually non-existent for soils in Hawaii and other tropical areas. Therefore, this study will contribute such information with the following objectives:

1. The effect of temperature on release of available nitrogen from slowly available nitrogen sources in different Hawaiian soils.
2. The effect on yield and uptake of nitrogen from slowly available nitrogen sources with corn (_Zea mays_ var. rugosa 'H-68') and Bermudagrass (_Cynodon dactylon_ XC. Magenisii var. "Sunturf").

REVIEW OF LITERATURE

Urea-form

Nitrogen fertilizer with controlled availability has been a goal of agriculturists for many years. Urea-formaldehyde (urea-form) was one of the early controlled release N product that became available for experimentation. In general it has been agreed (Arminger et al, 1951; Kralovec and Morgan, 1954; Mruk et al, 1957) that urea-form materials release nitrogen to plants at slow but uniform rates throughout the growing season. Fuller and Clark (1947) found that urea-form compounds hydrolyze chemically to ammonia only to a limited extent and that practically all of the decomposition of such compounds to ammonia and nitrate is brought about by microbial enzymes. These investigators believed that soil microorganisms can utilize the carbon of urea-formaldehyde in the same way that they use the carbon of soil organic matter. Winsor and Long (1958) showed that urea-form compounds decompose more readily in acid than in neutral or slightly alkaline soils. They suggested that the initial hydrolysis of an urea-form preparation in soils is chemical rather than biological. Laboratory (Killian, 1964; Long and Winsor, 1960; Owen et al, 1952; Yee and Love, 1946), greenhouse (Arminger et al, 1951 and Zimmerman et al, 1958) and field (Scarbrook, 1958) experiments demonstrated that the mineralization of urea-form compounds depends mainly upon their relative mole ratios of urea: formaldehyde and upon their method of manufacture. Mineralization was also found to depend on the physical and chemical properties of soils, such as texture and structure, pH, buffering capacity, and plant nutrient content, as well as on microbiological activities, and climatic conditions, including temperature and precipitation (Kralovec and Morgan, 1954).

The effect of soil temperature and pH on mineralization of urea-form materials has been reported by Basaraba (1964). He showed that these materials decomposed very slowly but progressively throughout the incubation period of 14 weeks, and that nitrate was the end product formed. The rate of nitrate production from the urea-form compounds was from 2 to 5% higher in soil with an initial pH of 5.7 than in soil having an initial pH of 7.0. Similar trends were reported by Kralovec and Morgan (1954), and Winsor and Long (1958), who showed that mineralization of urea-form fertilizer materials was more rapid in soil between pH 5.5 and 6.0 than between 7.0 and 7.8. At low temperatures, mineralization rates of the urea-form materials were very low but the compounds mineralized more rapidly as incubation temperatures were increased.

IBDU

Another slowly-available organic N compound which is now commercially available is Isobutylidene diurea (IBDU). This compound is a condensation product of urea and isobutyl aldehyde and has been developed in Japan (Hamamoto, 1966). It is slowly water-soluble and release of N is by dissolution which is controlled by granular size, with the larger the particle size, the smaller the quantity of IBDU dissolved. With IBDU, mineralization proceeds through successive steps: dissolution of solid IBDU in soil water, hydrolysis of dissolved IBDU to urea, and mineralization of urea to inorganic forms. The rate of mineralization of solid IBDU is determined by the velocity of dissolution, which depends on granular size, in addition to soil conditions, such as temperature, moisture, pH and soil type. Concerning the influence of temperature on the mineralization of IBDU powder, it has been reported that at 25^{o} C mineralization was rapid, but at 10^{o} C. the increase of inorganic nitrogen extended over eight weeks. Three to seven percent of urea from IBDU was detected after the first week at 25^{o} C. and 3 to 10% after four weeks at 10^{o} C. respectively. It has been shown that the dissolution velocity, which depends on granular size and the soil water content, was the main factor affecting mineralization of IBDU (Hamamoto, 1966).

Coated Materials

Within the past few years, considerable interest has developed in the possibility of controlling the rate of release of fertilizer constituents by an application of coating, or moisture barriers, to the surface of water-soluble fertilizer particles. Plastic (Beaton et al, 1967 and Brown and Volk, 1966), asphalt, and wax coatings have been used with varying degrees of success. Research has been carried out by the National Fertilizer Development Center of the Tennessee Valley Authority (TVA) for several years to develop a satisfactory coating for soluble fertilizers, using elemental sulfur and various other sealants. Oertli and Lunt (1962) reported on a series of experiments which evaluated several factors influencing the transfer of soluble fertilizers through the membranes of coated granules. They found that when these materials were placed in moist soil or water, water passed through the membrane and dissolved some of the fertilizer which in turn diffused out of the granule into the solution. It has been shown that transfer rates were influenced by coating thickness and temperature. Soil pH or microbiological activities seemed to have no effect on this process. The influence of soil moisture levels on transfer rates has been reported by Lunt and Oertli (1962). They found that moisture levels, exceeding the range of permanent wilting percentage to field capacity in a loam soil, did not appreciably affect the rate of transfer of nitrogen through the membrane of coated fertilizers mixed in the soil. Similar results have been reported by Ahmed et al. (1963). They also reported that the rate of release of soluble nutrient from the capsule was independent of the existence of a crop, soil texture, soil moisture between 25 and 100% of the field moisture capacity, and leaching of the soil.

Coating of urea granules with sulfur may provide an effective controlled-release nitrogen fertilizer at relatively low cost. Potential benefits are higher yield per unit of applied nitrogen and lower application cost. It may also have a residual value on sulfur-deficient soils (Rindt et al, 1968). Allen et al. (1971) reported that the rate of dissolution of sulfur-coated urea increased greatly with higher temperature of cropping or incubation. Dissolution rates of sulfur-coated urea were increased by a heavier coating with S, by inclusion of 0.5% coal tar oil microbicide in the coating, and by surface application. Apparent volatilization losses of surface-applied urea were severe, particularly at high incubation temperatures.

Natural Organic Nitrogen Sources

Among the natural organic nitrogen sources, the use of sewage sludge is becoming more widespread. Since the disposal of solid waste produced by municipal treatment plants is becoming an acute problem, its utility for agricultural benefit and land reclamation is being considered. Chemical analysis of sewage sludge indicates the presence of heavy metals in the solid phase. Long term sludge application may eventually lower crop yield because of a build-up of heavy metals. Horn et al. (1968) reported that an estimated 20 metric tons/ha/yr (10 T/A/Yr) of digested sludge suspension may be applied without creating a NO_3 ground water problem. Crops recovered N and P from sludge. High sludge rates increased total nitrogen in plants and addition of sludge usually increase crop yield.

Benefits of using sewage sludge have been reported by many investigators. Ali (1969) used sewage sludge for correction of Fe and Zn deficiencies in corn. He reported that corn yield, zinc uptake and DTPA-extractable Fe, Zn and Cu in a Zn-deficient soil increased from applications of 500-5000 ppm of sewage sludge. There was no significant increase in dry matter yield in an Fe-deficient soil (pH8) but there was a significant increase in DTPA-extractable Zn and Cu. Besides Zn, sludge addition enhanced the uptake of Mn by crops such as corn and sorghum (Braid et al, 1968). King (1971) reported that the results from an incubation study of liquid sludge in a sandy loam soil for 22 weeks showed that the levels of NH_4-N resulting from sludge application decreased and were not different from levels in the control treatment at eight weeks. Nitrate - N accumulation of 391 ppm of the applied N was found in the incorporated treatment at the end of 18 weeks. Gas losses of N (NH_3 volatilization and apparent denitrification) ranged from 16 to 22%. He also reported that applications of liquid sludge increased levels of N, Ca, Mg, Na, Mn and Zn; had little effect on P, B, Cu, Mo, and Ni; and reduced levels of K in the bermuda grass forage. Bermuda grass yield generally increased with increasing sludge application. In the 0-to 15-cm soil layer, sludge applications decreased levels of exchangeable Mg, K, and Mn, had no effect on Ca, and increased Zn and Na levels.

Comparison of Various N Sources

Allen et al, (1971) reported a very low N recovery of grass forage from urea-formaldehyde. Results from their experiment showed that single topdressed applications of granular sulfur-coated urea released N gradually over a long growth period. They found that release of N from sulfur-coated urea was too slow for satisfactory uptake of N by the 10 clippings of ryegrass over a 20-week period. Slow release properties of sulfur-coated urea were accentuated at high application rates. Uptake of N was essentially linear with 0, 160 and 320 p.p.m. applications of N, but became curvilinear with 640 p.p.m. Uptake distribution of N with high application rates of soluble N sources, such as ammonium nitrate and urea, tended to resemble that of sulfur-coated urea. A similar effect of sulfur-coated urea and uncoated soluble nitrogen fertilizers on yield and total nitrogen in fescue forage was reported by Mays and Terman (1969). Uncoated nitrogen fertilizers resulted in higher first cutting yields, which were higher in total nitrogen content. Sulfur-coated urea resulted in lower yields for first-cuttings and higher yields for later cutting than did the soluble N sources.

Beaton et al (1967) applied several sources of N at rates of 30, 60, 120 and 240 lb of N/A to orchard grass growing in a growth chamber.

They found that apparent recovery of coated urea was 75% which was equal to that of ammonium nitrate, but N recovery from urea-formaldehyde was only 41%. Yield and N uptake in the first harvest (25 days following fertilizer application) was greatest with soluble N fertilizers. Coated urea produced the highest yield and N uptake in the second (54 days after fertilizer application) and third (83 days) harvests. In the later stages of cropping, yields and N uptake from urea-formaldehyde increased and in the final four harvests the results obtained with urea-formaldehyde were among the highest. In the first cutting, all N sources, including coated urea and urea-formaldehyde, increased N uptake more than in the second cutting. Nitrogen uptake in the third and fourth cuttings was usually considerably less than in the first two harvests. The differences among the fertilizer treatments were small in the sixth harvest (260 days following fertilization). The results of coated urea reported by Beaton et al (1967) confirmed earlier studies of Lunt and Oertli (1962) and Oertli and Lunt (1962) who showed that coated fertilizers may provide a steady prolonged supply of nutrient, such as N, to plants for period exceeding 6 months.

Waddington et al (1971) applied IBDU, urea-form, and activated sludge to turfgrass. Color, clipping yield, N recovery and uniformity of growth during the growing season were used to evaluate turfgrass response for a period of five years. They found that these three sources of N gave relatively uniform growth. Yield and nitrogen recovery with IBDU treatments were considerably higher than in urea-form and sewage sludge treatments initially, but not in later years.

Moberg et al (1970) conducted grass experiments using slowly-available nitrogen sources and soluble N fertilizers at the rates of

3, 5 or 7 lb N/1000 ft^2. They reported that coated urea response following application was quicker and greater than that from urea-form and sewage sludge. IBDU showed good controlled release characteristic, but initial response after fertilization was slow. Residual effects of IBDU gave a green coloring earlier in the spring than in other treatments. Nitrogen recovery in clippings from applications of coated urea wqs 54% 22% from urea-form, 27% from sewage sludge, and 52% from IBDU, respectively. Recovery from soluble N fertilizer (urea) was 52%.

Similar results of IBDU over urea-form were also reported by McAlpine (1968). He reported that at rates of 0.45, 0.90 and 2.25 kg/ $92.9m^2$ (1,2 and 5 lb/1000 ft^2) IBDU was non-burning and more effective than urea-form products in maintaining turf quality in the greenhouse but was comparable to a urea-form product under field conditions at rates of 0.9 to 2.25 kg (2 to 5 lb) N/$92.9m^2$ (1000 ft^2). During a 90 day observation period, both urea-form and IBDU released insufficient nitrogen to be effective at the 0.9 and 1.35 kg N rates. The nitrogen release pattern of IBDU was inadequate at the 1.80 and 2.25 kg N rates during the first 21 days of growth of turf. After the delayed response, turf of high quality was maintained in the IBDU plots.

MATERIALS AND METHODS

Description of Soils Used

Uncultivated surface soils representing two different soil groups were collected from the Island of Oahu for this study. These soils, developed under two varying climatic conditions, and differing in physical, chemical and mineralogical properties are described by

Cline et al (1955) as shown in Table 1.

Table 1. Classification of the Experimental Soils

Series	Great Soil Group*/	Subgroup**/
Wahiawa	Low Humic Latosol	Tropeptic Eutrustox
Lualualei	Dark Magnesium Clay	Typic Chromustert

*/ Great Soil Group as classified by Cline et al (1955).

**/ Subgroup as presently classified by the U.S. Soil Survey Staff of the Soil Conservation Service.

A brief description of each of these two soils are as follows:

Wahiawa Silty Clay is a Low Humic Latosol (Tropeptic Eutrustox) which belongs to the Wahiawa Family and is derived from basaltic lavas under an annual rainfall of 30-40 inches at elevations ranging from 250-1200 feet above sea level. It has a low to moderate base saturation with a low buffering capacity. The soil has a high clay content but shows the physical properties of a silty clay loam. The clays are predominantly kaolinitic.

Lualualei Clay belongs to the Lualualei Family. It has developed from deep alluvium under an annual rainfall of 15-20 inches at an elevation of 20 feet about sea level. It has a high base saturation and high cation exchange capacity. The dominant mineral present in the clay fraction is montmorillonite. The soil has sticky and plastic properties that are associated with such clays.

The moisture equivalent, pH, total nitrogen and organic carbon data of these two soils are given in Table 2.

Table 2. Some Physical and Chemical Properties of the Experimental Soils*

Soil	Moisture Equivalent(%)	pH	Total N (%)	Organic C (%)	C:N
Wahiawa	32.6	5.4	0.174	1.44	8.2
Lualualei	41.7	7.7	0.099	1.06	10.7

*Data reported by Agarwal (1967), Tamimi (1964) and Thiagalingam (1967).

Nitrogen Sources

The six nitrogen sources used in this study are described in Table 3.

Table 3. Nature and Composition of Nitrogen Materials*/

Material	Nature	%N
Ammonium sulfate (reagent grade)	Soluble, readily available N	22
Activated sewage sludge	Natural organic N	3.4
Agriform	Urea-formaldehyde compound	40.4
Osmocote	Ammonium and nitrate N, coated with semi-permeable membrane	15.1
Sulfur-coated urea	Urea coated with sulfur	41.4
IBDU (Isobutylidene diurea)	Slightly soluble synthetic organic N compound	33.4

*The four slow release nitrogen materials (Agriform, Osmocote, sulfur-coated urea, and IBDU) were obtained from the Ultramar Fertilizer and Chemical Co. The activated sewage sludge was obtained from the Wahiawa Sewage Treatment Plant.

Laboratory Experiment

1. Preparation of Soil Samples

The soils used in the laboratory experiment were sieved through an 8-mesh steel sieve, and the sieved soils were stored in polyethylene bags before use throughout the study.

2. Experimental Procedure

One hundred grams (O.D. basis) each of Wahiawa and Lualualei soils were placed in 4 x 3 x 13 inch polyethylene bags for incubation at $7^{o}C$, room temperature ($27^{o}C \pm 2^{o}C$), and $40^{o}C$. Samples from each soil received the following N additions: (a) control (no N), (b) standard N source of ammonium sulfate added as an aqueous solution, (c) sieved particles of sewage sludge (smaller than 1mm), (d) Agriform, (e) Osmocote, (f) sulfur-coated urea, (g) IBDU. The nitrogen materials were added at the rate of 500 p.p.m. N. Soil and fertilizer were thoroughly mixed and the moisture content of all samples was adjusted to approximately moisture equivalent with distilled water. The bags were closed to essentially the volume of the soil and secured with rubber bands. Soil samples were analyzed for ammonium and nitrate nitrogen at 0, 1, 2, 4, 8, 15, and 24 week intervals by the method of Bremner (1965). All treatments were carried out in duplicates.

3. Analytical Procedure for Soil Analysis

Exchangeable ammonium and nitrate determinations were carried out by the method of Bremner (1965) with minor modifications. One hundred grams of soil sample was removed from the polyethylene bag to a 500 ml. Erlenmeyer flask for extraction with 1 N KCl (soil to

KCl solution ratio was 1:4), shaken for one hour on an end-to-end shaker, allowed to settle for 45 minutes, and then 10 ml. of the supernatant liquid was drawn off for the determination of NH_4- and NO_3-N with a micro-Kjeldahl distillation unit.

Ammonium was determined first. One-half gram of ignited heavy MgO was added to the extract, and the distilled NH_4 was received in 10 ml of mixed boric acid-indicator solution. After this distillation, about 1 ml of heavy mineral oil (to reduce foaming and creeping of Devada's Alloy up to the neck of the distillation flask) and 0.2 g of less-than-100 mesh Devada's Alloy was added to reduce NO_3 to NH_4 (this also includes NO_2) and the contents were redistilled into another receiving flask. The rate of distillation was set at 7-8 ml per minute. Thirty-five ml of distillate were collected for either NH_4 and NO_3 distillation and titrated with standard 0.005 N H_2SO_4.

4. Statistical Analysis:

Statistical analysis was carried out on an IBM 360- Computer for analysis of variance using a split, split, split plot randomized complete block design.

Greenhouse Experiments

1. Plants and N sources

Sweet corn, (*Zea mays* var. rugosa "H-68") and Bermudagrass (*Cynodon dactylon* XC. Magenisii var. "sunturf") were grown as indicator plants in the Wahiawa soil to study their response to nitrogen in the following N-containing materials: $(NH_4)_2SO_4$, sewage sludge, Agriform, Osmocote, sulfur-coated urea and IBDU which were previously described. A zero N treatment (control) was also included in the tests.

2. Experimental design

Experimental design was a randomized complete block with 2 replications.

3. Rate of N applied

Rates of nitrogen application were 200- and 400-lb of N/A.

4. Basal treatment

Calcium hydroxide, mono calcium phosphate, potassium sulfate, magnesium sulfate, ferrous sulfate, sodium molybdate and zinc sulfate were added as basal treatment at the rates equivalent to 500 lb/A of $Ca(OH)_2$, 1200 lb/A of P, 810 lb/A of K, 100 lb/A of Mg, 50 lb/A of $FeSO_4$, 9 lb/A of Mo and 20 lb/A of Zn, respectively.

5. Soil preparation and fertilization

a. Corn experiment

A single application of nitrogenous and basal fertilizers, except P, K and Zn, was applied before planting. Split applications of P, K, and Zn was carried out with 800 lb/A of P, 340 lb/A of K and 20 lb/A of Zn applied before planting and 400 lb/A of P, 270 lb/A of K and 1 lb/A of zinc chelate applied at the middle of the growing period.

Nitrogenous and basal fertilizers, except ferrous sulfate, sodium molybdate and zinc sulfate, were weighed and mixed dry with 40 lb of surface soil for each 5 gal. pot. Fe, Mo, and Zn were applied as a solution on the surface before planting. Five corn seeds per pot were planted on February 2, 1972. They were thinned to three plants per pot at 2 weeks. Water was applied daily at an amount to wet all the soil in the pot but with none flowing out the bottom of the container. An insecticide, "Spectracide", was applied once at 1 month after planting. Position of the pots in the greenhouse was changed periodically to reduce border effects.

b. Grass experiment

The time and rate of the first application of P and K for grass were the same as those for corn, but the second application was applied two months after planting at the same rate for corn.

On February 1, 1972, stolons of "Sun Turf" Bermuda grass was grown in flats with 27 lb of Wahiawa surface soil prepared in the same way as in the corn experiment. The grass was clipped one inch above the soil at 30-day intervals for a total of three cuttings. Watering was done the same way as in the corn experiment. An insecticide, "Spectracide", was applied biweekly.

6. Harvest and plant sample preparation

a. Corn experiment

Whole corn plants were harvested at the tasseling stage on March 31, 1972. The harvested samples were dried at 65^{o}C in a blower oven until constant weight was obtained, weighed, and then ground in a Wiley Mill in preparation for total nitrogen (include NO_3) analysis by the Kjeldahl method.

b. Grass experiment

The grass was clipped one inch above the soil at 30-day intervals for three cuttings. Tissue sample preparation was the same as in the corn experiment.

7. Plant analysis

One gram of oven dry plant tissue was placed in a 800 ml

Kjeldahl flask, and digested with 40 ml concentrated H_2SO_4 and 2 g of salicylic acid for at least 1 hour with occasional mixing. Five grams of sodium thiosulfate was added, mixed and digested at low heat for 15 minutes, then allowed to cool. One ml of 1% selenious acid and 5 g of Na_2SO_4 were added and digestion of the sample was continued until the digest was clear. Organic nitrogen is converted to ammonia by digestion with concentrated H_2SO_4 in the presence of selenium and sodium sulfate. Organic matter is simultaneously completely oxidized. Nitrate is reduced to ammonia by reaction with salicylic acid followed by thiosulfate before digestion with concentrated acid.

The completely digested sample was cooled, diluted with about 300 ml water, mixed and then cooled. One hundred ml of 1:1 NaOH and a few granules of mossy zinc were added. The flask was connected to the distillation unit immediately. The ammonium formed is distilled and collected in 50 ml of 4% boric acid-indicator mixture in a 500 ml Erlenmeyer flask. Two hundred ml of distillate was collected and titrated with standard 0.07 N H_2SO_4.

8. Statistical analysis

a. Corn experiment

Vegetable yield, percent nitrogen and nitrogen uptake were statistically analyzed by analysis of variance based on randomized complete block design and means were compared using the Duncan's multiple range test at a .05 level of significance.

b. Grass experiment

Yield, percent nitrogen and nitrogen uptake for individual cuttings were statistically analyzed by analysis of variance based on randomized complete block design but cumulative yields percent N and N uptake from three cuttings were done by sing a Factorial 2 x 3 x 7 randomized complete block design. Means were compared by using the Duncan's multiple range test at .05 level of significance. The computer program and documentation written by Douglas Garwood of the Department of Horticulture, the Pennsylvania State University, was used in this study.

RESULTS AND DISCUSSION

Experiment I. Laboratory Experiment. Effect of Temperature on Mineralization of Slowly-Available Nitrogen Fertilizers in Lualualei and Wahiawa Soils.

The conversion of organic forms of nitrogen to the inorganic forms is known as nitrogen mineralization. As a consequence of mineralization, ammonium and nitrate (and occasionally nitrite) nitrogen accumulate and organic nitrogen disappears. These products are formed from two distinct microbiological processes: ammonification, in which ammonium is formed from organic compounds, and nitrification, which is the oxidation of ammonium to nitrate.

The amounts of NH_4-N, NO_3-N and total available nitrogen released in the Wahiawa soil at 7^oC., room temperature ($27^oC \pm 2^oC$. incubation are shown in Tables 4, 5, and 6 and in the Lualualei soil in Tables 7, 8, and 9, respectively.

The analysis of variance of NH_4-N, NO_3-N and NH_4+NO_3 are given in Tables 10, 11, and 12, respectively. As shown in these tables, soil, fertilizer, temperature and time of incubation were all found to have significant influence on the amounts of NH_4-N, NO_3-N and total available (NH_4+NO_3) nitrogen.

1. Incubation at 7^oC.

   a. Nitrogen transformation in the Wahiawa soil.

   The amount of NH_4-N from the 500 ppm. $(NH_4)_2SO_4$ treatment remained almost constant up to the 16 week period but at the 24 week period it decreased to 372 ppm. (Figure 1). The NH_4-N produced from the slowly-available nitrogen fertilizers increased with time of incubation. Among the slowly-available nitrogen fertilizers, sulfur-coated urea produced the greatest amount of NH_4-N (239 ppm.) within 4 weeks (Figure 3). Sewage sludge and Osmocote which produced similar amounts of NH_4-N had significantly lower amounts of NH_4-N than sulfur-coated urea (Table 4). The sewage sludge reached its maximum value of NH_4-N (159 ppm.) at 7^oC. at the eighth week period (Figure 2) but IBDU (Figure 1) and Osmocote (Figure 3) did so at the 16 week period. As shown in Table 4, Agriform was the least effective fertilizer in producing NH_4-N in the Wahiawa soil at 7^oC. incubation. It reached its maximum value of NH_4-N at the eighth week period. The amounts of NH_4-N in the soils treated with slowly-available nitrogen fertilizers decreased after the maximum values were obtained.

At 7^oC. incubation, there was no considerable difference in the amounts of NO_3-N produced in the fertilizer - treated soils and in the control soil within 16 weeks, except with the Osmocote treatment (Table 5). The amount of NO_3-N from the Osmocote treatment in the Wahiawa soil increased with time of incubation (Figure 3). At the 24 week period, 137 ppm. of NO_3-N was produced with the Osmocote treatment. This was followed by sewage sludge, IBDU, sulfur-coated urea, Agriform, $(NH_4)_2SO_4$ and control treatments in which 96, 89, 87, 63, 31 and 4 ppm of NO_3-N was obtained respectively (Table 5).

As shown in Figure 4 the amount of available nitrogen (NH_4+NO_3) generally increased with the addition of slowly-available nitrogen fertilizers up to the 16 week period of incubation. A decrease of NH_4+NO_3 nitrogen was found in all treatments after the after the sixteenth week, with the exception of Osmocote and IBDU. The level of NH_4+NO_3 nitrogen in the $(NH_4)_2SO_4$ treatment remained almost constant throughout the 16 weeks of incubation. The maximum values of available nitrogen found in the Wahiawa soil at 7^oC. incubation were 518, 270, 242, 192, 167, 141, and 39 ppm. from $(NH_4)_2SO_4$, Osmocote, sulfur-coated urea, IBDU, sewage sludge, Agriform and control treatments respectively (Table 6).

b. Nitrogen transformation in the Lualualei soil.

As shown in Table 7 the amount of NH_4-N from the $(NH_4)_2SO_4$ treatment and the control decreased with time of incubation. All slowly-available nitrogen fertilizers produced more NH_4-N than the control soil. Among the slowly-available fertilizers, sulfur-coated urea produced the highest amount of NH_4-N (236 ppm.) within 8 weeks (Figure 3). The Osmocote-treatment soil showed increased NH_4-N with increasing time of incubation. The maximum value of NH_4-N from Osmocote treatment (130 ppm.) was less than that of sulfur-coated urea. The IBDU treatment increased in NH_4-N content (85 ppm.) up to the 16 week period. This maximum content of NH_4-N was less than those of sulfur-coated urea and Osmocote at the same period (Table 7). The maximum NH_4-N value from sewage sludge was 77 ppm. at the eighth week period (Figure 2). Among the slowly-available nitrogen fertilizers, Agriform produced the smallest amount of NH_4-N. After the first week of incubation the amount of NH_4-N in this treatment never exceeded 24 ppm. (Figure 2 and Table 7).

The NO_3-N in the Lualualei soil at 7^oC. increased with the addition of nitrogen fertilizers and with time of incubation (Table 8). This soil showed an increase of NO_3-N up to 165 ppm.

with Osmocote, followed by sulfur-coated urea, IBDU, $(NH_4)_2SO_4$, sewage sludge and Agriform which had 101, 83, 80, 61 and 41 ppm., respectively, at the 24 week period. As indicated in Figures 1, 2 and 3 the Lualualei soil generally showed faster nitrification than the Wahiawa. All nitrogen fertilizers produced more NO_3-N in the Lualualei soil than in the Wahiawa, except the sewage sludge and Agriform treatments at the 24 week of incubation (Figures 1, 2 and 3).

At 7°C. incubation the amount of available nitrogen (NH_4 and NO_3) in the Lualualei soil treated with $(NH_4)_2SO_4$ generally decreased gradually after the eighth week (Figure 4). As shown in Figure 4 the amount of NH_4+ NO_3 in the Agriform and sewage sludge treatments increased continuously for eight weeks, then leveled off. The same trend was found in the IBDU-treated soil, but the mineralization slowed down after the sixteenth week. Osmocote was the only fertilizer that continuously released available nitrogen up to 24 weeks. A non-uniform release curve was found in sulfur-coated urea treated soil, with the highest peak at the eighth week. The following decreasing order of maximum values of available nitrogen was found in the Lualualei soil at 7°C. incubation: Osmocote, sulfur-coated urea, IBDU, sewage sludge, and Agriform (Table 9). The amounts of NH_4+NO_3 nitrogen shown in Table 9 was lower than those of the Wahiawa soil (Table 6) for the comparable treatment and period, except for the Osmocote and SCU treatments (see also Figure 4).

2. Incubation at room temperature.

a. Nitrogen transformation in the Wahiawa soil.

The NH_4-N from the $(NH_4)_2SO_4$ treatment incubated at room temperature decreased faster than it did at the 7°C. incubation

(Figure 1). The slowly-available nitrogen fertilizers increased their NH_4-N production at room temperature more rapidly than at 7^oC. (Figures 1, 2 and 3). These results indicated that ammonification rate increased with increasing temperature. As shown in Table 4, the greatest increase of NH_4-N (209 ppm.) in the Wahiawa soil at room temperature was found in the sulfur-coated urea treatment within two weeks. Agriform produced 202 ppm. of NH_4-N within 4 weeks. The rate of release of NH_4-N from Osmocote was slower than that from sewage sludge and IBDU; however, this fertilizer continued to release NH_4-N up to 8 weeks resulting in a higher amount of NH_4-N accumulated in this soil than in the sewage sludge and IBDU treatments (Table 4). As shown in Figures 1, 2, and 3 the NH_4-N accumulated in this soil at room temperature was generally lower than at 7^oC., especially at the longer periods of incubation.

The following decreasing order of NO_3-N production was found in the Wahiawa soil at the 16 week period: sulfur-coated urea, osmocote, $(NH_4)_2SO_4$, IBDU, Agriform, sewage sludge and the control (Table 8). The amounts of NO_3-N accumulated in the Wahiawa soil at room temperature was higher than at 7^oC., (Figures 1, 2, and 3).

As shown in Figure 4 and Table 6 the amounts of available nitrogen in the Wahiawa soil treated with slowly-available nitrogen fertilizers increased with time of incubation. It was also found that the rate of mineralization at room temperature was faster than at 7^oC. incubation. Osmocote and sulfur-coated urea were mineralized completely within 16 weeks. The highest values of NH_4 + NO_3 nitrogen found in the Wahiawa soil treated with IBDU, and sewage sludge were 354 and 238 ppm. at the 24 and 16 week periods, respectively. A non-uniform release curve was found in the Wahiawa soil treated with Agriform at room temperature (Figure 4). The highest value (334 ppm.) of available nitrogen released from this compound was at the fourth week of incubation. The $(NH_4)_2SO_4$ treatment also showed a non-uniform release curve which indicated some kind of nitrogen loss during the incubation study with the Wahiawa soil at room temperature. After the sixteenth week of incubation the amounts of available nitrogen from all treatments dropped except from the IBDU treatment, indicating loss of nitrogen in this soil.

b. Nitrogen transformation in the Lualualei soil.

The results shown in Figure 1 and in Table 7 indicate that the rate of decrease of NH_4-N from the $(NH_4)_2SO_4$ treatment in the Lualualei soil at room temperature was faster than in the Wahiawa soil. The slowly-available nitrogen fertilizers were ammonified in the Lualualei soil at an almost equal rate as in the Wahiawa, but the amounts of NH_4-N in the Lualualei soil were smaller (Figure 1, 2 and 3). The greatest increase of NH_4-N was found in the Lualualei soil treated with sulfur-coated urea followed by IBDU, Osmocote, sewage sludge and Agriform (Table 7). The highest amounts of NH_4-N were found in the slowly-available nitrogen fertilizer-treated soil only at the first week of incubation, except with Agriform and Osmocote treatments (Figures 1, 2, and 3). The amounts of NH_4-N found in the Agriform (Figure 2) and Osmocote (Figure 3) treatments at the second and fourth week of incubation respectively, were higher than those found in the first week. After each fertilizer reached its highest value of NH_4-N, this form started to decrease rapidly. The rates of decrease of NH_4-N in the sulfur-coated urea and IBDU treatments were slower than in the others (Table 7).

The amounts of NO_3-N accumulated in the Lualualei soil at room temperature were higher than at 7^oC (Figures 1-3 and Table 8). The amount of NO_3-N increased with application of nitrogen fertilizers and with time of incubation up to 16 weeks. This indicated a similar effect of temperature on the amount of NO_3-N followed by Osmocote, sulfur-coated urea, IBDU, Agriform, sewage sludge, in an order of decreasing magnitude (Table 8). As shown in Figures 1, 2 and 3, the NO_3-N accumulated in the Lualualei soil at room temperature was higher than that in the Wahiawa soil for the comparable treatment and period, except in Agriform and sewage sludge treatments.

The mineralization of slowly-available nitrogen fertilizers in the Lualualei soil at room temperature increased with time of incubation up to sixteen weeks in most cases (Table 9). The values of NH_4+NO_3 nitrogen at the end of the sixteenth week were in the following decreasing order: Osmocote, sulfur-coated urea, IBDU, Agriform, and sewage sludge (Table 9). As shown in Figure 4 the amounts of available nitrogen in the Lualualei soil at room temperature were lower than those found in the Wahiawa soil for the comparable treatment and period, except in the IBDU treatment. After the sixteenth week of incubation the mineralization curves for nitrogen fertilizers leveled off or even dropped (Figure 4).

3. Incubation at 40^{o}C.

a. Nitrogen transformation in the Wahiawa soil.

The NH_4-N in the $(NH_4)_2SO_4$ treatment decreased much less rapidly at 40^{o}C. than at room temperature (Figure 1). The slowly-available nitrogen fertilizers produced the highest amounts of NH_4-N and at the most rapid rate as compared to those at room temperature and 7^{o}C. incubations (Figures 1, 2 and 3). The following highest values of NH_4-N were found in the Wahiawa soil at 40^{o}C. incubation: 402 ppm. from IBDU at the 16 week period; 306 ppm. from Osmocote at the 24 week period; and, 292 ppm from sewage sludge and 204 ppm. from Agriform both at the eight week period (Table 4).

As shown in Table 5 the NO_3-N in the Wahiawa soil increased with time of incubation. The rate of increase of NO_3-N was slow up to eight weeks. After this period the nitrification rate increased. Most of the nitrogen fertilizers showed very little increase in their NO_3-N production over the control soil within the first four weeks, except in the Osmocote treatment which produced NO_3-N continuously up to 16 weeks. Great nitrification of IBDU (Figure 1) and Agriform (Figure 2) was started at the eighth and sixteenth week of incubation at 40^{o}C. respectively. The NO_3-N from the $(NH_4)_2SO_4$ treatment was generally not higher than in the control soil throughout the 24 weeks (Table 5). Rapid nitrification was found in the sewage sludge treatment after the sixteenth week of incubation. The maximum amounts of NO_3-N in the Wahiawa soil at 40^{o}C. were as follows: 258 ppm. from Osmocote treatment at the sixteenth week; 268, 214, 191, 157, 131 and 100 ppm.

from sewage sludge, IBDU, Agriform, sulfur-coated urea, control and $(NH_4)_2SO_4$ treatments respectively at the 24 week period (Table 5).

The highest amounts of NH_4+NO_3 nitrogen were found in the Wahiawa soil at 40^{o}C. incubation, as compared to those at room temperature and 7^{o}C. incubation, except in the sulfur-coated urea and Osmocote treatments (Table 6). These two compounds released less available nitrogen at 40^{o}C. incubation than at room temperature. Non-uniform release curves in the Wahiawa soil at 40^{o}C. incubation were found with Osmocote and sulfur-coated urea treatments (Figure 4). As indicated in Figure 4, Osmocote was mineralized the most, followed by IBDU, sulfur-coated urea, Agriform and sludge in an order of decreasing magnitude.

b. N transformation in the Lualualei soil.

The same effect of temperature as found in the Wahiawa soil at 40^{o}C. incubation was found in the Lualualei soil (Figures 1, 2 and 3). The NH_4-N in the $(NH_4)_2SO_4$ treatment in the Lualualei soil at 40^{o}C. decreased almost as rapidly as that at room temperature (Figure 1). The most rapid rate of increase of NH_4-N was found in the soil treated with Osmocote, followed by sulfur-coated urea, sewage sludge, IBDU, and Agriform (Table 8). The highest values of NH_4-N from slowly-available nitrogen fertilizer-treated soils were found at the first week of incubation, except for IBDU and Agriform treatments (Figures 1, 2 and 3). The ammonification of IBDU proceeded up to four weeks of incubation (Figure 1). Most of the highest values of NH_4-N found in the Lualualei soil at 40^{o}C. were higher than in comparable treatments at room temperature and $7^oC.$, except in the sulfur-coated urea treatment (Table 7).

As shown in Table 8 all nitrogen fertilizers in the Lualualei soil produced more NO_3-N at $40^oC.$ than at room temperature. All nitrogen-treated soils showed complete nitrification within 16 weeks. The following highest amounts of NO_3-N were found in the Lualualei soil at the sixteenth week period: 526 ppm. from Osmocote, 502 ppm from $(NH_4)_2SO_4$, 460 ppm. from IBDU; 448 ppm. from sulfur-coated urea, 298 ppm. from Agriform and 235 ppm. from sewage sludge. The results shown in Figures 1, 2, and 3 indicated that nitrification in the Lualualei soil was better than in the Wahiawa at all temperatures and that nitrification in the form soil was highest at $40^oC.$

The amounts of available nitrogen (NH_4+NO_3) in the Lualualei soil increased with increasing temperature up to $40^oC.$ (Figure 4 and Table 9). The amounts of NH_4+NO_3 released in this soil increased with time of incubation up to the 16 week period, except in the sewage sludge treatment which reached its maximum value at the fourth week period and then leveled off. The 500 ppm of nitrogen in Osmocote and IBDU were mineralized almost completely within 16 weeks (Table 9). The soil treated with sulfur-coated urea, Agriform and sewage sludge accumulated 463, 305 and 239 ppm. of NH_4+NO_3, respectively, within 16 weeks. As indicated in Figure 4, mineralization of slowly-available nitrogen fertilizers in the Lualualei soil at all temperatures was generally lower than in the Wahiawa soil, except in the IBDU treatments.

Discussion

The results shown in Figures 1, 2 and 3 generally are in agreement with those of previous investigators reviewed by Harmsen and Schreven (1955). This indicated that ammonification took place at all temperatures from $7^{o}C$. up to $40^{o}C$., the highest level conducted in this investigation. The increase in the amount of NH_4-N release was due to the effect of temperature on nitrogenous compound decomposition, either by chemical (Singh and Kanehiro, 1970) or biological activities (Harmsen and Schreven, 1955). The amounts of NH_4-N produced from incubated samples at the two higher temperatures were found to be very great at the beginning of the incubation experiment and decreased rapidly after a short while because of nitrification.

Nitrate accumulation increased with increasing temperature, but there was a difference in the optimum temperature requirement for nitrification in the Wahiawa and the Lualualei soils. Nitrification in the Lualualei soil increased with temperature up to $40^{o}C$., but in the Wahiawa soil NO_3-N production decreased at $40^{o}C$. These results agree with the earlier reports of Thiagalingam (1967) and Frederic (1956, 1957). These investigators concluded that nitrate formation took place at all temperatures up to $40^{o}C$. and the optimum temperatures for nitrification of NH_4-N lies between $25^{o}C$. and $35^{o}C$. The reason for nitrification in the Lualualei and Wahiawa soils was due to the fact that the Lualualei soil has developed in a warmer climatic zone than has the Wahiawa; therefore, microorganisms in the former performed nitrification better at higher temperatures than in the Wahiawa soil. Nitrification in the Wahiawa soil was lower than in the Lualualei at all temperatures. Many investigators have reported that nitrification is low in acid soils (Basaraba, 1964; Fuller and Clark, 1947; Winsor and Long, 1956, 1958). The Wahiawa soil has a pH of 5.4 which is lower than that of the Lualualei (7.7). Therefore, the acidic condition of the Wahiawa is likely to be one of the reasons for the lower nitrification in this soil as compared to the Lualualei soil.

The rate of nitrate production varied with the material undergoing transformation. Alexander (1967) stated that in environments having a near neutral reaction, nitrates appear more rapidly from ammonium salts than from organic nitrogen compounds, whereas nitrates are formed faster from organic materials in certain acid soils. Eno and Blue (1957) also reported that when urea is hydrolyzed, the resulting ammonia increases the pH so that the formation of nitrate in an acid soil is also greater for urea than for $(NH_4)_2SO_4$. The results from the 7^{o}C. and 40^{o}C. incubation of the Wahiawa soil agree with these earlier investigators. As shown in Table 5, the amount of NO_3-N in the $(NH_4)_2SO_4$-treated soil at 7^{o}C. incubation was lower than those with sewage sludge, Agriform, sulfur-coated urea and IBDU up to the 8 week period. No such effect of nitrogen carrier was found in this soil at room temperature because this temperature is the optimum condition for nitrification.

The results obtained from Osmocote and sulfur-coated urea (Figure 3) agree with those reported by Oertli and Lunt (1962) and Ahmed _et al._ (1963). They reported that the soluble nutrients diffused from the coated fertilizers. The rate of release was independent of pH of the soil and the microbial activities; but directly related to temperature. As shown in Tables 4 and 7 the sulfur-coated urea treatment produced

NH_4-N in both soils at the most rapid rate and at the highest amounts at all temperatures as compared to the other slowly-available nitrogen fertilizers. Urea is believed to be diffused readily from sulfur-coated urea granules; therefore, large amounts of urea were presumably present, even at 7^oC., thus resulting in highest hydrolysis of NH_4-N. Urea hydrolysis is very rapid, even at low temperature, and the rate of hydrolysis increases with increasing temperature (Alexander, 1967). Since increasing temperature would be expected to stimulate the rate of release of urea from sulfur-coated urea and also the rate of urea hydrolysis, the NH_4-N in the sulfur-coated urea-treated soils increased with an increase in temperature. The NO_3-N may also be released from Osmocote granules by diffusion. Therefore, the accumulation of NO_3-N was found in the Wahiawa soil treated with Osmocote at 7^oC. and 40^oC. incubation throughout the 24 week period. Temperature will likely effect an increase in rate of release from Osmocote by expanding coated membranes which may result in larger pores, thus facilitating the diffusion of soluble salts. These reasons might explain why the NO_3-N in both soils (Tables 5 and 8) generally increased with increasing temperature. Since the soluble nutrients are released form the coated fertilizer (Osmocote and sulfur-coated urea) by diffusion, the microbiological activities might have less influence on the mineralization of these two fertilizers, resulting in highest amounts of available nitrogen released in both soils as compared to the other slowly available nitrogen fertilizers. Even though pH and microbiological activities have less influence in the rate of release of soluble nutrients from the coated materials (Oertli and Lunt, 1962), there was a difference in the amounts of NH_4+NO_3 between the Whiawa and the

Lualualei soils (Figure 4). This difference might be due to the transformation of NH_4-N after it had been released. This transformation is a biological process in which soil, temperature and moisture have a significant influence upon the amount of NO_3-N released. The mineralization of nitrogen from sulfur-coated urea was lower than from Osmocote (Figure 4). The microbicide added to sulfur-coated urea may be a factor in explaining this lower mineralization.

The results obtained from the Agriform treatment (Figures 2 and 4) agree with those reported by Kralovec and Morgan (1954), Winsor and Long (1958) and Basaraba (1964). They reported that mineralization of urea-formaldehyde compound was more rapid in soils between pH 5.5 and 6.0 than in those between 7.0 and 7.8 and the compound mineralized more rapidly as incubation temperature was increased. Winsor and Long (1956, 1958) reported that urea-formaldehyde compounds differed from natural or-anic material in that their decomposition in soil appeared to be favored by acidity and the rate of decomposition decreased with increasing chain-length of the compounds. Kralovec and Morgan (1954) reported that nitrification of urea-formaldehyde was more rapid in a soil having an initial pH value of 6.1 than in soils of pH 5.6 and 7.3. The results for the accumulation of nitrate in Agriform-treated soils support those of Kralovec and Morgan in that the higher amounts of NO_3-N at 7^{o}C. and room temperature was found in the Wahiawa (pH 5.4) than in the Lualualei soil (pH 7.7). The incomplete mineralization of Agriform shown in Figure 4 may be due to the presence of long-chain methylene urea which is difficult to break down by microorganisms, as reported by Winsor and Long (1958).

The results obtained from the IBDU treatment shown in Figures 1 and 4 and agree with those reported by Hamamoto (1966). He reported that the rate of mineralization of this compound is controlled by two factors: one is the dissolution and the other is the mineralization after the dissolution. Granule size, in addition to the soil condition, such as temperature, moisture, pH and soil type, were reported as the factors that influence the mineralization of IBDU. He showed that at $25^{o}C$. mineralization was fast, 3 to 7% of urea from IBDU being found at the first week at $25^{o}C$. and 3 to 10% of urea being found at four weeks at $10^{o}C$. The results in Figures 1 and 4 indicated that the mineralization of IBDU increased with increasing temperature. An effect of soil type on the mineralization of IBDU was also found in this study; IBDU was mineralized faster in the Lualualei in the Lualualei soil than in the Wahiawa, as shown in Figure 1.

As shown in Figures 2 and 4, sewage sludge and Agriform were quite similar in their ammonification, nitrification, and mineralization. The reason for these results is not known. In general nitrification in the Wahiawa soils treated with sewage sludge was slightly faster than in those treated with Agriform. Harmsen and Ven Schreven (1955) reported that nitrification was increased with the addition of lime. The sewage sludge contains lime which might have some effect in increasing pH of the Wahiawa soil so that nitrification with sewage sludge proceeds faster than with Agriform. In the case of the Lualualei soil, such a lime effect may not be the reason because this soil has a pH of 7.7 and the addition of lime should not have an effect on nitrification of sludge. The incomplete mineralization of sewage sludge at $7^{o}C$. may be due mainly to the cold temperature effect on microbial activities, but at room temperature and at $40^{o}C$., this may be due to the presence of an undegradable form of nitrogen in this compound.

The results in Figures 1-4 indicated some loss of nitrogen in both soils at all temperatures. This was more evident in the Lualualei than in the Wahiawa soil. The Lualualei soil has 2:1 clay which has been shown to fix ammonium (Tamimi, 1964; Mikami, 1966). It has a pH above neutrality and some loss of nitrogen may be due to volatilization at high temperature as reported by Jewitt (1942), Martin and Chapman (1951), Jackson and Chang (1947). The loss of nitrogen from the Lualualei soil may be explained by the reasons given by these foregoing investigators.

It is not known assuredly whether loss of N in the Wahiawa soil occurred through volatilization of ammonia or through elemental nitrogen as reviewed by Harmsen and van Schreven (1955). These authors proposed that loss of elemental nitrogen from acid soil occurs when nitrite comes in contact with ammonium salts, with amines, or even with nitrogen-free sulfur compounds. Addition of ammonium sulfate to slightly acid soils therefore may sometimes result in loss of gaseous nitrogen. They also reported evidences of losses of 30% of nitrogen added to soil samples as $(NH_4)_2SO_4$ within 89 weeks of incubation at optimum aeration in a soil of pH 6.0 but it is not known assuredly whether this loss occurred through volatilization of ammonia. Loss of ammonia ceased when there was no loss of moisture. The Wahiawa soil has 1:1 clay and is slightly acid. Therefore, the conditions of this soil for such losses of nitrogen as reviewed by the previous investigators are not confirmed. These losses of nitrogen may be one of the reasons why the mineralization of nitrogen fertilizers appeared to be lower in the Lualualei soil than in the Wahiawa, even though it was superior in nitrification. Incomplete recoveries of slowly-available nitrogen, especially those producing urea, might be due also to loss of nitrogen during incubation.

Table 4. Effect of temperature on NH_4-N production from nitrogen sources in the Wahiawa soil.

Treatment	Temp.	INCUBATION PERIOD (WEEKS) 0	1	2	4	8	16	24
		ppm. N						
Control	7°C	25	30	31	27	32	16	1
Soil + $(NH4)_2SO_4$		499	500	495	495	471	500	372
Soil + sewage sludge		26	43	58	93	159	144	56
Soil + Agriform		33	47	60	56	79	59	19
Soil + Osmocote		33	41	46	76	150	153	133
Soil + sulfur-coated urea		27	91	119	239	198	183	71
Soil + IBDU		30	51	64	86	116	152	103
Control	Room Temp.	25	10	4	0	4	0	11
Soil + $(NH4)_2SO_4$		499	498	484	299	278	230	188
Soil + sewage sludge		26	113	67	0	17	5	17
Soil + Agriform		33	71	56	202	46	6	18
Soil + Osmocote		33	92	97	116	123	100	70
Soil + sulfur-coated urea		27	177	209	161	147	108	104
Soil + IBDU		30	100	65	26	12	10	36
Control	40°C	25	43	41	44	55	17	6
Soil + $(NH4)_2SO_6$		499	527	510	516	508	454	374
Soil + sewage sludge		26	199	232	263	292	247	54
Soil + Agriform		33	151	190	198	204	178	153
Soil + Osmocote		33	232	239	262	290	207	306
Soil + sulfur-coated urea		27	146	203	402	191	207	299
Soil + IBDU		30	149	186	232	249	330	273

Table 5. Effect of temperature on NO_3-N production from nitrogen sources in the Wahiawa soil.

Treatment	Temp.	INCUBATION PERIOD (WEEKS) 0	1	2	4	8	16	24
					ppm. N			
Control	7°C	0	4	3	5	7	19	4
Soil + $(NH_4)_2SO_4$		0	6	12	6	12	18	31
Soil + sewage sludge		0	3	3	4	8	21	96
Soil + Agriform		0	4	4	4	12	29	63
Soil + Osmocote		8	13	19	34	87	104	137
Soil + sulfur-coated urea		0	0	5	3	9	34	87
Soil + IBDU		0	0	5	4	11	35	89
Control	Room Temp.	0	12	30	39	51	56	42
Soil + $(NH_4)_2SO_4$		0	34	39	129	237	320	245
Soil + sewage sludge		0	10	78	169	216	233	181
Soil + Agriform		0	14	54	132	107	233	187
Soil + Osmocote		8	64	116	199	241	429	364
Soil + sulfur-coated urea		0	20	80	172	380	441	348
Soil + IBDU		0	18	67	133	204	249	318
Control	40°C	0	5	13	10	26	114	131
Soil + $(NH_4)_2SO_4$		0	10	11	22	13	93	100
Soil + sewage sludge		0	2	10	3	15	94	268
Soil + Agriform		0	6	10	8	54	187	191
Soil + Osmocote		8	91	177	193	237	258	194
Soil + sulfur-coated urea		0	6	24	13	75	58	157
Soil + IBDU		0	7	19	13	153	153	214

Table 6. Effect of temperature on available (NH_4+NO_3) nitrogen production from nitrogen sources in the Wahiawa soil.

Treatment	Temp.	INCUBATION PERIOD (WEEKS) 0	1	2	4	8	16	24
					ppm. N			
Control	7°C	25	34	34	32	39	35	5
Soil + $(NH_4)_2SO_4$		499	506	507	501	483	518	403
Soil + sewage sludge		26	46	61	97	167	165	152
Soil + Agriform		33	51	64	60	141	88	82
Soil + Osmocote		42	53	65	110	237	257	270
Soil + sulfur-coated urea		27	91	124	242	208	217	158
Soil + IBDU		30	51	89	90	126	187	192
Control	Room Temp.	25	27	34	39	55	56	53
Soil + $(NH_4)_2SO_4$		499	532	523	428	515	550	433
Soil + sewage sludge		26	123	145	169	232	238	198
Soil + Agriform		33	85	110	334	153	239	205
Soil + Osmocote		42	156	213	315	364	529	438
Soil + sulfur-coated urea		27	197	288	332	527	549	452
Soil + IBDU		30	118	133	159	216	259	354
Control	40°C	25	47	54	54	81	131	137
Soil + $(NH_4)_2SO_4$		499	537	521	538	521	547	474
Soil + sewage sludge		26	201	242	267	307	341	322
Soil + Agriform		33	157	200	206	258	365	344
Soil + Osmocote		42	323	416	456	527	365	500
Soil + sulfur-coated urea		27	152	227	415	266	265	456
Soil + IBDU		30	156	205	245	402	483	487

Table 7. Effect of temperature on NH_4-N production from nitrogen sources in the Lualualei soil.

Treatment	Temp.	INCUBATION PERIOD (WEEKS) 0	1	2	4	8	16	24
					ppm. N			
Control	7°C	13	4	6	3	4	3	0
Soil + $(NH_4)_2SO_4$		513	505	491	490	475	398	288
Soil + sewage sludge		13	12	32	43	77	73	35
Soil + Agriform		11	24	21	17	14	10	0
Soil + Osmocote		12	22	11	31	81	109	130
Soil + sulfur-coated urea		12	186	95	175	236	93	74
Soil + IBDU		10	16	21	30	46	85	57
Control	Room Temp.	13	3	9	0	11	6	4
Soil + $(NH_4)_2SO_4$		513	418	309	239	58	3	4
Soil + sewage sludge		13	57	7	6	11	6	5
Soil + Agriform		11	22	43	4	5	4	6
Soil + Osmocote		12	22	43	54	32	11	6
Soil + sulfur-coated urea		12	164	113	18	74	15	7
Soil + IBDU		10	78	24	13	7	7	7
Control	40°C	13	0	2	5	4	6	2
Soil + $(NH_4)_2SO_4$		513	394	369	235	211	7	4
Soil + sewage sludge		13	103	103	41	20	4	4
Soil + Agriform		11	11	35	4	3	7	1
Soil + Osmocote		12	200	138	99	42	18	0
Soil + sulfur-coated urea		12	152	104	79	69	15	7
Soil + IBDU		10	19	104	197	156	35	6

Table 8. Effect of temperature on NO_3-N production from nitrogen sources in the Lualualei soil.

Treatment	Temp.	0	1	2	4	8	16	24
		INCUBATION PERIOD (WEEKS)						
		ppm. N						
Control	7^oC	0	9	11	12	11	13	17
Soil + $(NH_4)_2SO_4$		12	11	16	20	28	55	80
Soil + sewage sludge		11	10	16	18	22	26	61
Soil + Agriform		21	6	13	18	27	42	41
Soil + Osmocote		22	20	22	51	101	150	165
Soil + sulfur-coated urea		21	9	15	19	28	55	101
Soil + IBDU		3	6	14	19	26	60	83
Control	Room Temp.	0	12	9	19	14	16	15
Soil + $(NH_4)_2SO_4$		12	51	120	639	445	499	347
Soil + sewage sludge		11	15	74	158	138	162	133
Soil + Agriform		21	49	89	105	146	180	158
Soil + Osmocote		22	52	126	235	359	466	367
Soil + sulfur-coated urea		21	55	146	229	334	432	348
Soil + IBDU		3	35	129	273	389	421	343
Control	40^oC	0	11	21	17	37	52	64
Soil + $(NH_4)_2SO_4$		12	42	39	202	248	502	291
Soil + sewage sludge		11	25	136	200	220	235	187
Soil + Agriform		21	52	91	136	229	298	165
Soil + Osmocote		22	52	232	340	446	526	368
Soil + sulfur-coated urea		21	55	172	289	351	448	256
Soil + IBDU		3	81	81	149	348	460	292

Table 9. Effect of temperature on available (NH_4+NO_3) nitrogen production from nitrogen sources in the Lualualei soil.

Treatment	Temp.	INCUBATION PERIOD (WEEKS) 0	1	2	4	8	16	24
		ppm. N						
Control	7°C	13	13	17	15	15	16	17
Soil + $(NH_4)_2SO_4$		525	516	507	510	503	443	342
Soil + sewage sludge		24	27	48	61	102	100	96
Soil + Agriform		32	30	34	35	41	51	41
Soil + Osmocote		34	42	33	77	181	259	295
Soil + sulfur-coated urea		33	194	110	194	264	142	175
Soil + IBDU		13	21	35	49	72	145	140
Control	Room Temp.	13	15	18	19	25	22	19
Soil + $(NH_4)_2SO_4$		525	469	429	478	503	502	351
Soil + sewage sludge		24	72	81	123	149	168	138
Soil + Agriform		32	71	132	109	151	184	164
Soil + Osmocote		34	74	169	288	391	482	373
Soil + sulfur-coated urea		33	219	260	248	408	447	355
Soil + IBDU		13	113	153	286	396	428	352
Control	40°C	13	11	23	22	41	58	66
Soil + $(NH_4)_2SO_4$		525	436	408	437	459	508	295
Soil + sewage sludge		24	128	239	241	240	239	191
Soil + Agriform		32	63	126	140	232	305	166
Soil + Osmocote		34	252	370	439	488	544	368
Soil + sulfur-coated urea		33	207	276	308	420	463	263
Soil + IBDU		13	100	185	396	504	495	298

Table 10. Analysis of variance on the effect of temperature on NH_4-N production from nitrogen sources in the Wahiawa and Lualualei soils.

Source of variation	DF	Mean square
Replication	1	43.537
Soil (A)	1	830,779.599*
Error (a)	1	11.435
Temperature (B)	2	221,528.883**
AXB	2	174,623.696**
Error (b)	4	34.211
Fertilizer (C)	6	1,183,851.363**
AXC	6	24,247.376**
BXC	12	41,071.285**
AXBXC	12	8,589.563**
Error (c)	24	87.119
Time (D)	6	45,243.780*
AXD	6	27,736.531
BXD	12	21,987.446
CXD	36	28,941.407
AXBXD	12	9,638.330
AXCXD	36	5,700.513
BXCXD	72	145.097
Error (d)	60	189.289

* Significance at 0.05 level of probability.

** Significance at 0.01 level of probability.

Table 11. Analysis of variance on the effects of temperature on NO_3-N production from nitrogen sources in the Wahiawa and Lualualei soils.

Source of variation	DF	Mean square
Replication	1	1,185.757**
Soil (A)	1	329,582.043**
Error (a)	1	0.287
Temperature (B)	2	813,194.393**
AXB	2	151.700**
Error (b)	4	793.573
Fertilizer (C)	6	181,659.240**
AXC	6	26,667.717**
BXC	12	32,309.827**
AXBXC	12	9,557.119**
Error (c)	24	573.925
Time (D)	6	468,180.982**
AXD	6	24,170.737**
BXD	12	67,002.813**
CXD	36	15,183.519**
AXBXD	12	13,261.776**
AXCXD	36	4,095.775**
BXCXD	72	4,978.292**
Error (d)	60	650.369

** Significance at 0.01 level of probability.

Table 12. Analysis of variance on the effects of temperature on the NH_4+NO_3 production from nitrogen sources in the Wahiawa and Lualualei soils.

Source of variation	DF	Mean square
Replication	1	4,154.709
Soil (A)	1	132,570.138*
Error (a)	1	660.080
Temperature (B)	2	731,507.709**
AXB	2	4,091.056
Error (b)	4	1,074.223
Fertilizer (C)	6	1,625,327.032**
AXC	6	11,719.094**
BXC	12	57,820.366**
AXBXC	12	7,421.352**
Error (c)	24	779.922
Time (D)	6	397,785.576**
AXD	6	13,678.614**
BXD	12	28,358.535**
CXD	36	44,955.260**
AXBXD	12	8,281.509**
BXCXD	72	77,238.032**
Error (d)	60	1,285.078

*Significance at 0.05 level of probability.

**Significance at 0.01 level of probability.

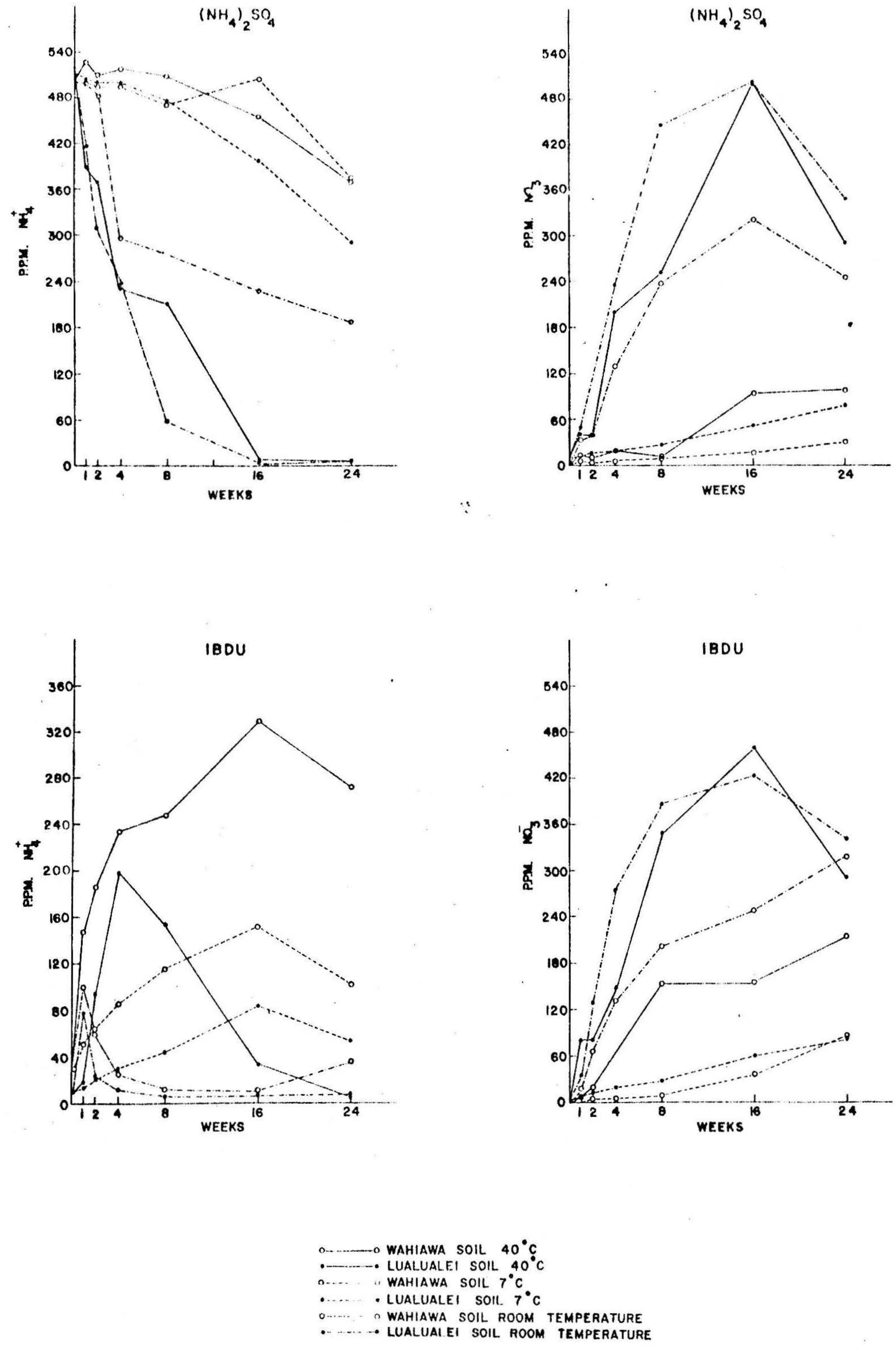

Fig. 1. Effect of temperature on NH_4-N and NO_3-N produced from $(NH_4)_2SO_4$ and IBDU.

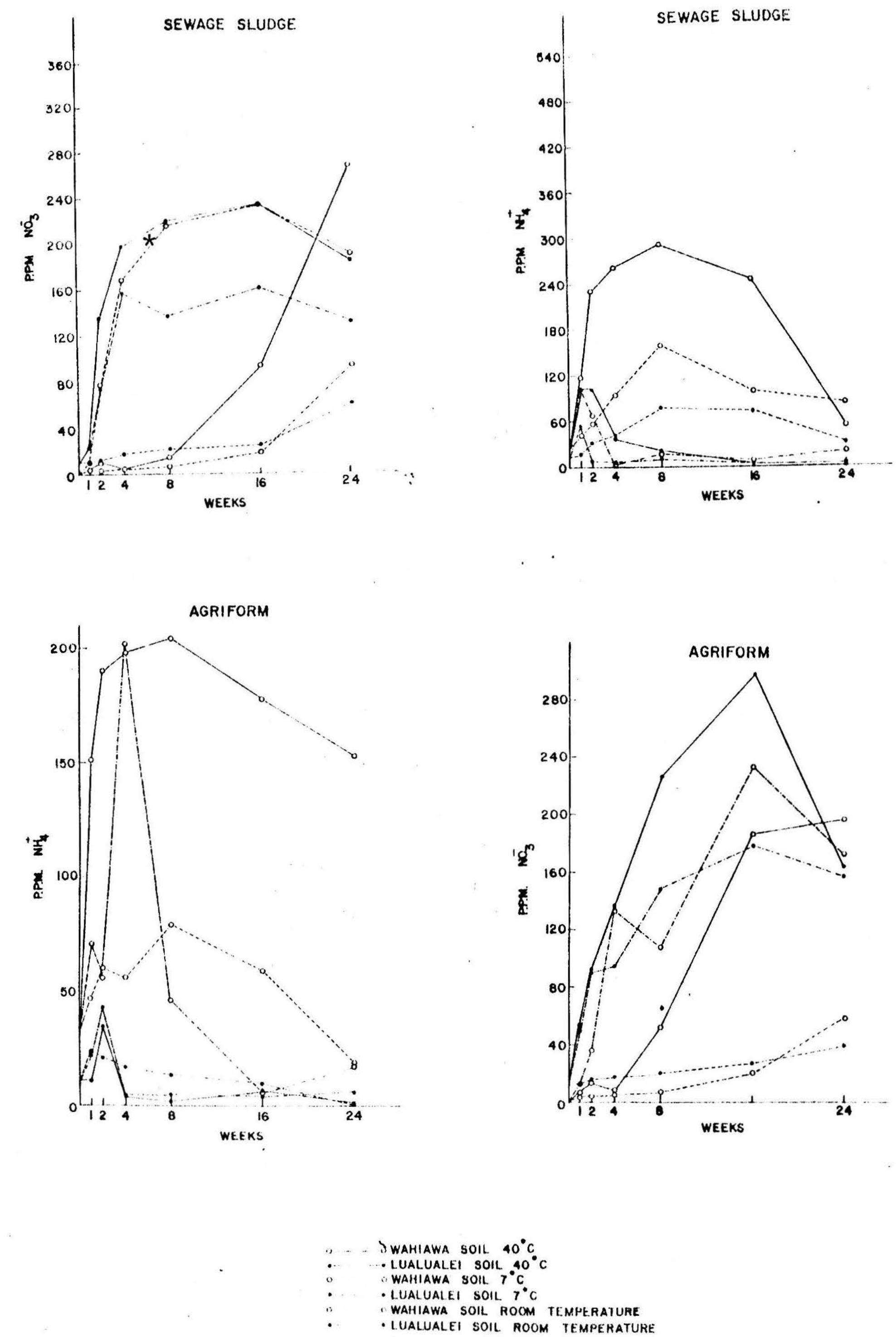

Fig. 2. Effect of temperature on NH_4-N and NO_3-N produced from sewage sludge and Agriform.

* This curve is at room temperature (it was mistakenly drawn as curve for 7°C.)

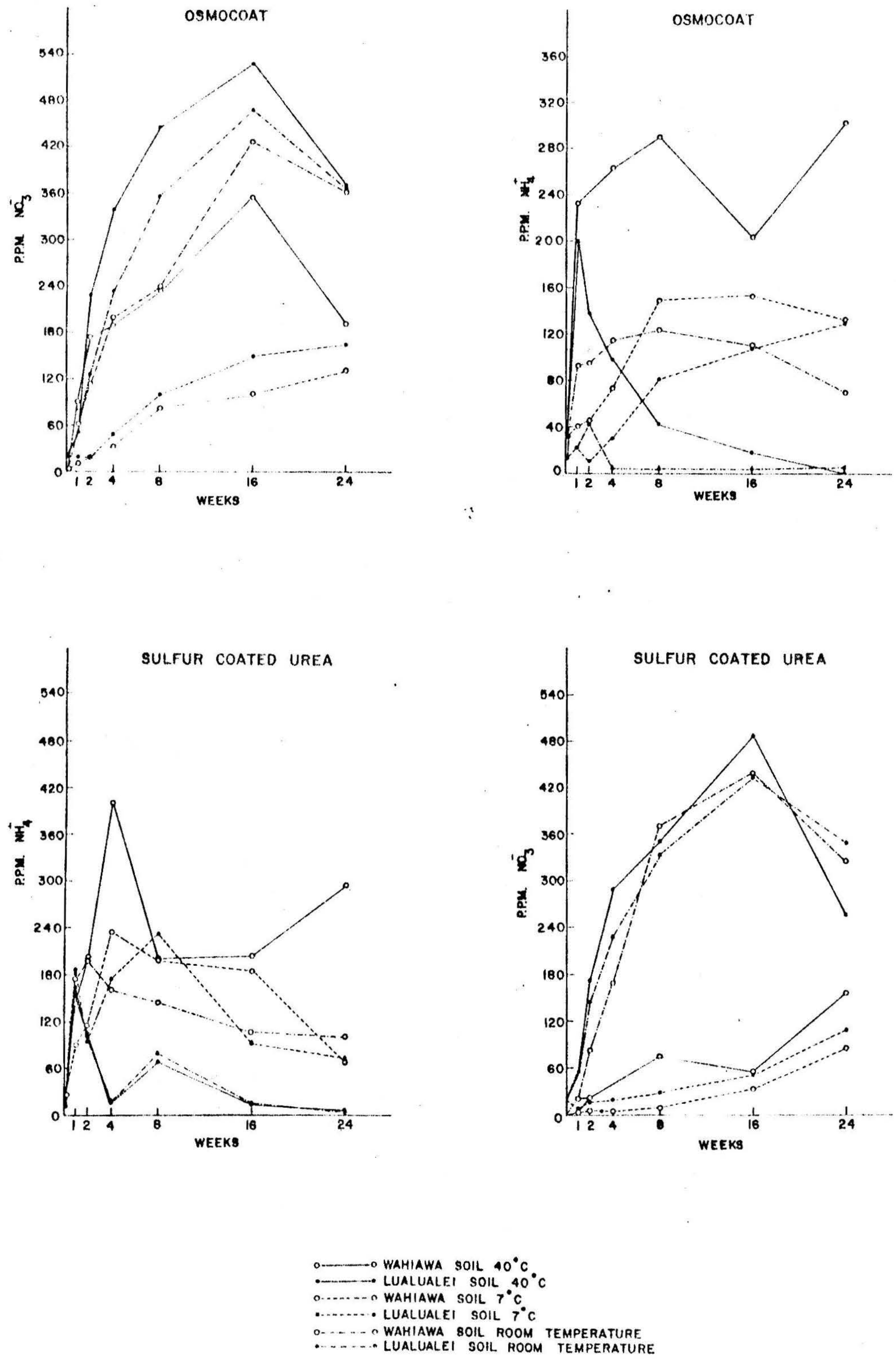

Fig. 3. Effect of temperature on NH_4-N and NO_3-N produced from Osmocote and sulfur-coated urea. ("Osmocoat" should be corrected to read "Osmocote").

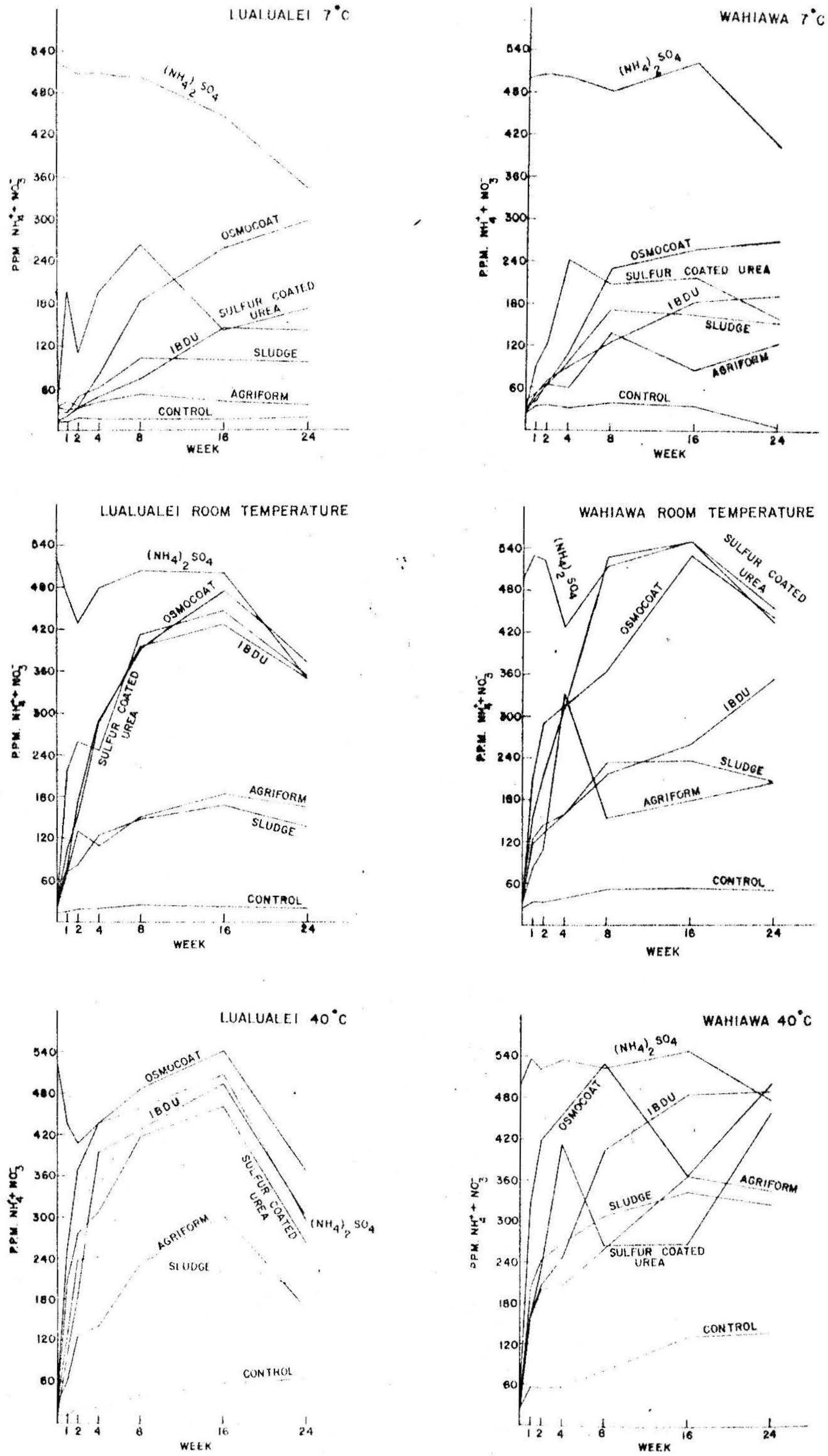

Fig. 4. Effect of temperature on $NH_4 + NO_3$ produced from nitrogen sources in the Lualualei and Wahiawa soils.

Experiment II. Greenhouse Experiments. Effect of Slowly-available Nitrogen Fertilizers on Growth, Nitrogen Content and Uptake of Nitrogen in Corn and Bermudagrass.

A. Corn Experiment

Data on vegetative yield expressed in dry weight (later referred to as dry weight), percent nitrogen and N uptake of corn are presented in Tables 13, 14 and 15, respectively. Nitrogen fertilizers, rates of application and their interactions were found to have a highly significant influence on the amount of dry weight, percent nitrogen and N uptake of corn as shown in Tables 16, 17 and 18.

1. Dry weight of corn

Dry weight of corn increased with all nitrogen fertilizer applications when compared to the control (Table 13). Application of 400 lb N/A significantly increased yield over application of 200 lb N/A, except in the Osmocote treatment. At any one level of N applied, there was no significant difference on the effect of N sources in influencing yield.

2. Percent nitrogen

There was no difference in percent N between the control and in the N treatments at 200 lb N/A, but there was a significant increase of percent total N at 400 lb N/A (Table 14). At this level percent N in corn was increased by application of $(NH_4)_2SO_4$, sewage sludge, Agriform, Osmocote and IBDU when compared to the control. The percent of N in the Osmocote treatment was nearly twice that of the control. Sulfur-coated urea was the only fertilizer that did not increase N content at this 400 lb N/A rate.

3. N uptake

N uptake of corn was significantly increased with all N fertilizer applications and also with the higher application rate (Table 15). N uptake at the 200 lb N/A level had significantly higher uptake over that of the control, but among the fertilizers there was no significant difference. Similarly, N uptake was increased with 400 lb N/A over 200 lb N/A application. Sources of N did not significantly affect N uptake, except in the Osmocote treatment where uptake was highest.

4. Performance of corn

As shown in Figure 5 there was a difference in the performance of corn between the 200 and 400 lb N/A. treatments. Corn at the 400 lb N/A rate grew better than that at the 200 lb N/A rate in terms of color of leaves, size of plant, and in overall vigor. Even though there was no difference in the height of corn between the 200 lb (No. 8) and 400 lb (No. 9) N/A Osmocote treatments, the color of the leaves did differ. The performance of corn with an application of 200 lb N/A of Osmocote was better than that with a comparable application of $(NH_4)_2SO_4$ (No. 2).

Discussion

Data in Table 13 suggest an obvious advantage of N fertilizer application in increasing growth of corn. The results show about a three times higher yield with N application when compared to the control. However, there were no significant differences in yield among the different nitrogen sources. A one hundred percent increase in N application (increase level of N applied from 200 to 400 lb N/A) increased yield by about 50%. Application of N at the 200 lb N/A rate showed no significant effect on percent N in the plant over the control (Table 14). However, at the 400 lb N/A rate there was a significant increase of percent N over that of the 200 lb N/A treatment and the control. Since both rates of N application resulted in an increased N uptake/pot (Table 15), it is concluded that the reason for the non increase in N concentration with the 200 lb. rate is due to a dilution effect, arising from increased growth.

The highest N content in tissue was obtained with the 400 lb/A application of Osmocote, while among the other N treatments there was no significant difference. The laboratory work showed that Osmocote in the Wahiawa soil at 40^{o}C. incubation released the highest amount of available nitrogen as compared to the other N fertilizers and this compound released the maximum N value at the eighth week period. This might explain why corn, with the application of Osmocote, contained more N than with the application of other N fertilizers.

B. Grass Experiment

Data on yield and N uptake for three cuttings in bermudagrass are presented in Figures 6 and 7. Analyses of variance for the effects of nitrogen fertilizers, rates and cuttings on yield, percent nitrogen and N uptake are shown in Tables 19, 20 and 21, respectively. Main effect of nitrogen sources, cuttings and rates of application on dry weight, percent N and N uptake of bermudagrass are shown in Tables 22, 23 and 24, respectively. The effect of nitrogen source on percent N and N uptake of bermudagrass at three cuttings are shown in tables 27 and 28, respectively.

Table 13. Effect of six nitrogen sources on vegetative yield of corn using two rates of nitrogen.

Material	Pounds N applied/A 200	400	Mean
	Dry weight of corn, gm/pot*		
Check	51.95 d	46.70 d	49.32 d
$(NH_4)_2SO_4$	157.80 c	235.35 a	196.54 a
Sewage sludge	162.55 c	203.20 ab	182.87 a
Agriform	154.10 c	223.60 a	188.85 a
Osmocote	182.25 bc	204.80 ac	193.52 a
Sulfur-coated urea	164.85 c	217.30 ab	191.07 a
IBDU	155.90 c	226.35 a	191.12 a
Mean	147.06	193.90	

*Means followed by different letters are significantly different at the 0.05 level.

Table 14. Effect of six nitrogen sources on percentage nitrogen in corn using two rates of nitrogen.

Material	Pounds of N applied/A 200	400	Mean
	%N		
Check	0.820	0.820	0.822
$(NH_4)_2SO_4$	0.790	0.985	0.887
Sewage sludge	0.785	0.915	0.850
Agriform	0.820	1.025	0.922
Osmocote	0.720	1.505	1.112
Sulfur-coated urea	0.745	0.880	0.812
IBDU	0.745	1.070	0.907
Mean	0.775	1.029	

Table 15. Effect of six nitrogen sources on N uptake in corn using two rates of nitrogen.

Material	Pounds of N applied/A 200	400	Mean
	N uptake of corn, mg N/pot*		
Check	426.50 d	385.70 d	406.10 d
$(NH_4)_2SO_4$	1,242.95 c	2,321.75 a	1,782.35 b
Sewage sludge	1,285.75 bc	1,865.10 abc	1,575.42 b
Agriform	1,262.00 bc	2,291.85 a	1,776.92 b
Osmocote	1,312.20 bc	3,097.00 e	2,204.60 a
Sulfur-coated urea	1,226.00 c	1,931.55 ab	1,578.77 b
IBDU	1,184.80 c	2,403.00 a	1,793.90 ab
Mean	1,134.31	2,042.28	

* Means followed by different letters are significantly different at the 0.05 level.

Table 16. Analysis of variance for the effects of nitrogen fertilizers and rates on dry weight of corn.

Source of variation	DF	Mean square
Fertilizer (A)	6	11,488.012**
Rate (B)	1	15,359.773**
AXB	6	897.862**
Replication (C)	1	0.700
Error	13	259.560

** Significance at 0.01 level.

Table 17. Analysis of variance for the effects of nitrogen fertilizers and rates on percent nitrogen in corn.

Source of variation	DF	Mean square
Fertilizer (A)	6	0.041
Rate (B)	1	0.453*
AXB	6	0.064
Replication (C)	1	0.022
Error	13	0.015

* Significance at 0.05 level.

Table 18. Analysis of variance for the effects of nitrogen fertilizers and rates on nitrogen uptake of corn.

Source of variation	DF	Mean square
Fertilizer (A)	6	1,262,123.449**
Rate (B)	1	5,770,794.009**
AXB	6	326,373.430*
Replication (C)	1	97,786.860
Error	13	94,435.231

* Significance at 0.05 level.
** Significance at 0.01 level.

Table 19. Analysis of variance for the effects of nitrogen fertilizers, rates and cuttings on dry weight of bermudagrass.

Source of variation	DF	Mean square
Fertilizer (A)	6	45.592**
Cutting (B)	2	218.506**
AXB	12	24.554**
Rate (C)	1	333.246**
AXB	6	11.816**
BXC	2	34.192**
AXBXC	12	6.567**
Replication (D)	1	2.046
Error	41	1.354

** Significance at 0.01 level.

Treatments:

1. Control

2 and 3. $(NH_4)_2SO_4$ at 200 and 400 lb N/A rates respectively.

4 and 5. Sewage sludge at 200 and 400 lb N/A rates respectively.

8 and 9. Osmocote at 200 and 400 lb N/A rates respectively.

Fig. 5. Appearance of corn with sewage sludge (top) and Osmocote (bottom) treatments as compared to control and $(NH_4)_2SO_4$ treatments. (Refer to opposite page for description of numbered treatments.)

1. Grass yield

Grass yield was affected the most by the rate of N applied, followed by the number of cutting and kind of fertilizer used (Table 19). Dry weight of grass was significantly higher with fertilizer treatments as compared to the control (Table 22). There was a significant increase in yield at the 400 lb N/A application over that of the 200 lb N/A application (Table 24). At the 200 lb N/A rate there was no significant difference among nitrogen sources, except in the Agriform treatment which resembled the control (Table 25). At the 400 lb N/A rate, sulfur-coated urea was superior to other N fertilizers but not significantly different from Osmocote.

Three cuttings were made in this experiment. Generally, the first cutting gave the highest yield as compared to subsequent cuttings (Figure 6 and Table 26). At the 200 lb N/A level, however, the yield of the second cutting with sulfur-coated urea was significantly higher than that of the first. At the 200 lb N/A application, $(NH_4)_2SO_4$ gave a higher yield in the second cutting as compared to the first. Also, the yield in the second cutting from the sulfur-coated urea treatment was similar to the yield obtained in the first.

A comparison of the yields of the third cutting showed that sewage sludge at the 400 lb N/A rate gave significantly higher yield than the other fertilizer treatments but did not differ significantly from sulfur-coated urea.

2. Percent nitrogen

The number of cutting, kind, and rate of fertilizer applied affected percent nitrogen significantly (Table 20). Percent N in grass in the three cuttings are shown in Table 27. The first cutting showed a significantly higher percent of N in grass, as compared to the other subsequent cuttings (Tabl 23). At the first cutting, there was no significant difference in N percentage among $(NH_4)_2SO_4$, Osmocote, and IBDU treatments, but they did give a higher percentage N than Agriform and sewage sludge treatments (Table 27). All fertilizer treatments gave significantly higher percent of N than the control. In the second cutting there was no significant difference in N percentage, among nitrogen sources, except in the $(NH_4)_2SO_4$ treatment which resembled the control.

3. N uptake

N uptake in grass was affected the most by the cutting followed by the rate of N applied and the kind of fertilizer used (Table 21). N uptake of grass was highest in the first cutting and decreased in the subsequent cuttings (Figure 7 and Table 23). There was a significant increase in N uptake at the 400 lb N/A application over that of the 200 lb N/A application (Table 24).

There was a significant difference in N.uptake among fertilizers treatments at the three cuttings as shown in Table 28. At the first cutting Osmocote and IBDU gave significantly higher N uptake than $(NH_4)_2SO_4$, sewage sludge, Agriform and sulfur-coated urea. The latter four treatments gave equal N uptake. At the second cutting the highest N uptake was obtained from the sulfur-coated urea treatment. There was no significant difference in N uptake among $(NH_4)_2SO_4$, Osmocote and IBDU but N uptake from $(NH_4)_2SO_4$

treatment was significantly higher than those from sewage sludge and Agriform. At the third cutting, sewage sludge gave the highest N uptake but this was not significantly different from that of the sulfur-coated urea treatment. The fertilizer treatments that gave significantly higher N uptake than the control were sewage sludge, sulfur-coated urea and Agriform. There was no significant difference in N uptake among Osmocote, IBDU, $(NH_4)_2SO_4$ and control treatments.

4. Performance of Bermudagrass.

As shown in Figure 8 (second cutting), an increase in N rate resulted in an improvement of grass quality and all products yielded superior grass quality than was obtained in the control. At the third cutting (Fig. 9) there was a pronounced decrease in grass quality as compared to the second cutting (Fig. 8). All fertilizers showed no improvement in grass quality except sewage sludge, sulfur-coated and Agriform, which showed superior quality than the control at the 400 lb N/A rate.

Discussion

Available nitrogen released at $40^{o}C$ from the various nitrogen fertilizers in the laboratory incubation experiment seems to be related to the dry weight, percent N, and N uptake obtained in the grass experiment. The temperature of the soil in which the grass was grown was found to reach $38^{o} \pm 2^{o}C$. during the early afternoon hours when the grass experiment was carried out. It is therefore logical to conclude that available nitrogen release patterm from nitrogen sources in the grass experiment would most closely resemble N release pattern at $40^{o}C$.

than at room temperature ($28^0 \pm 2^0C$) or at 7^0C. of the laboratory experiment.

The foregoing may in part explain some of the results obtained in the grass experiment. The slowly available nitrogen fertilizers used in this study are reported to be slow-release fertilizers (Beaton et al 1967, Killian et al 1964, Mruk et al 1957, McAlpine 1968, Rindt et al, 1968) and thus one would expect that grass yield and performance would increase with subsequent cuttings. The results of this study, especially as shown so vividly in Figures 6 and 7, did not show such a trend. The first cutting gave the highest yield, highest percent N and highest N uptake (Table 23) as compared to the other two subsequent cuttings. This may likely be due to the previously mentioned high temperature ($38^0 \pm 2^0C$) under which this experiment was carried out. It appears that temperature plays a large role in determining release of available N from slow-release N sources.

Among the slow-release N sources, Osmocote, sulfur-coated urea and IBDU generally gave higher yields, higher percent N, and higher N uptake (Table 22) than sewage sludge and Agriform treatments. A close look at the data however reveals that yield, percent N and N uptake with Osmocote and IBDU treatments generally decrease more than with the sewage sludge and Agriform treatments in the third cutting. Sulfur-coated urea remains relatively high in all three categories in all three cuttings. Figure 9 for the third cutting shows that at the 400 N/A level performance of the sulfur-coated urea treatment is still high, followed by that of the sewage sludge and Agriform treatments. It should be mentioned that there may be side-benefits to the sulfur-coated urea and sewage sludge treatments in the way of sulfur and micronutrients benefits (Ali, 1969 and Horn et al 1968).

Yield, percent N and N uptake obtained in this grass experiment at the first cutting correlated well with those of corn experiment.

Table 20. Analysis of variance for the effects of nitrogen fertilizers, rates and cuttings on percent N of Bermudagrass.

Source of variation	DF	Mean Square
Fertilizer (A)	6	1.330**
Cutting (B)	2	28.450**
AXB	12	0.664
Rate (C)	1	6.298*
AXB	6	0.347
BXC	2	0.690
AXBXC	12	0.099
Replication (D)	1	0.008
Error	41	0.069

*Significance at 0.01 level.
**Significance at 0.05 level.

Table 21. Analysis of variance for the effects of nitrogen fertilizers, rates, and cuttings on nitrogen uptake of Bermudagrass.

Source of variation	DF	Mean Square
Fertilizer (A)	6	50,399.68**
Cutting (B)	2	474,320.47**
AXB	12	33,874.94**
Rate (C)	1	426,864.56**
AXB	6	20,006.34**
BXC	2	153,376.32**
AXBXC	12	12,991.35**
Replication (D)	1	1,594.54
Error	41	2,897.71

**Significance at 0.01 level.

Table 22. Main effect of nitrogen sources on dry weight, percent nitrogen and nitrogen-uptake of Bermudagrass.*

N source	Dry weight, g/flat	%N	N uptake, mg N/flat
Control	0.63 c	1.38 c	9.10 e
$(NH_4)_2SO_4$	5.00 b	2.05 b	116.01 cd
Sewage sludge	5.57 b	2.03 b	133.93 bc
Agriform	3.81 c	1.95 b	92.68 d
Osmocote	6.08 a	2.29 a	202.71 a
Sulfur-coated urea	6.27 a	2.25 a	163.31 ab
IBDU	5.18 b	2.39 a	178.11 a

* Means in the same column followed by different letters are significantly different at the 5% level.

Table 23. Main effect of cuttings on dry weight, percent nitrogen and nitrogen uptake of Bermudagrass.*

Cutting	Dry weight g/flat	%N	N uptake mg N/flat
1	7.40 a	3.19 a	275.09 a
2	4.71 b	1.68 b	84.16 b
3	1.82 c	1.28 c	26.40 c

* Means in the same column followed by different letters are significantly different at the 5% level.

Table 24. Main effect of rates of nitrogen application on dry weight, percent nitrogen and nitrogen uptake of bermudagrass.*

Pound N/A	Dry weight g/flat	%N	N uptake mg N/flat
200	2.26 b	1.77 b	57.26 b
400	6.63 a	2.32 a	119.84 a

* Means in the same column followed by different letters are significantly different at the 5% level.

Table 25. Interaction effect of nitrogen source by rate of application on dry weight of Bermudagrass (g/flat)*

N source	Interaction component Pound N applied/A 200	 400
Control	0.66 f	0.59 f
$(NH_4)_2SO_4$	3.27 e	6.66 cd
Sewage sludge	3.68 e	7.46 bcd
Agriform	1.28 f	6.35 d
Osmocote	3.73 e	8.43 ab
Sulfur-coated urea	3.29 e	9.25 a
IBDU	2.65 e	7.70 bc

* Figures represent averages for three cuttings. Means followed by different letters are significantly different at the 5% level.

Table 26. Dry weight of Bermudagrass for three cuttings for two levels of nitrogen from different nitrogen sources (g/flat).*

N source	Rate lb N/A	Cutting 1		Cutting 2		Cutting 3	
Control		0.87	n	0.59	n	0.57	n
$(NH_4)_2SO_4$	200	4.1	ghijk	5.3	efghi	0.5	n
	400	8.2	cd	11.2	b	0.7	n
Sewage sludge	200	7.5	de	1.9	klmn	1.7	lmn
	400	10.9	b	5.0	fghi	6.5	def
Agriform	200	1.3	mn	2.0	klmn	0.5	n
	400	10.0	bc	5.1	fghi	4.0	hijkl
Osmocote	200	6.9	def	3.7	ijkl	0.6	n
	400	17.3	a	5.4	efghi	2.6	jklmn
Sulfur-coated urea	200	3.3	ijklm	6.0	defgh	0.5	n
	400	11.8	b	11.2	b	4.8	fghij
IBDU	200	5.4	efghi	1.7	lmn	0.9	n
	400	15.6	a	6.3	defg	1.2	mn

* Means in the table followed by different letters are significantly different at the 5% level.

Table 27. Effect of nitrogen sources on percent nitrogen of Bermudagrass at three cuttings.*

N sources	Cutting 1	Cutting 2	Cutting 3
Control	1.75 d	1.33 b	1.07 a
$(NH_4)_2SO_4$	3.70 ab	1.31 b	1.14 a
Sewage sludge	2.90 c	1.74 a	1.44 a
Agriform	2.89 c	1.74 a	1.20 a
Osmocote	3.77 ab	1.87 a	1.23 a
Sulfur-coated urea	3.34 bc	1.98 a	1.42 a
IBDU	3.97 a	1.78 a	1.42 a

* Means in the same column followed by different letters are significantly different at the 5% level.

Table 28. Effect of nitrogen sources on nitrogen uptake in Bermudagrass at three cuttings (mg N/flat).*

N sources	Cutting 1	Cutting 2	Cutting 3
Control	13.08 c	8.04 d	6.16 d
$(NH_4)_2SO_4$	235.5 b	105.96 b	6.51 d
Sewage sludge	277.39 b	61.07 c	63.34 a
Agriform	184.49 b	63.86 c	29.68 bc
Osmocote	499.15 a	86.38 bc	22.59 cd
Sulfur-coated urea	272.60 b	185.95 a	42.38 ab
IBDU	443.35 a	77.87 bc	13.10 cd

* Means in the same column followed by different letters are significantly different at the 5% level.

Treatments:

1. Control

2 and 3. $(NH_4)_2SO_4$ at 200 and 400 lb N/A respectively.

4 and 5. Sewage sludge at 200 and 400 lb N/A respectively.

6 and 7. Agriform at 200 and 400 lb N/A respectively.

8 and 9. Osmocote at 200 and 400 lb N/A respectively.

10 and 11. Sulfur coated urea at 200 and 400 lb/A respectively.

12 and 13. IBDU at 200 and 400 lb N/A respectively.

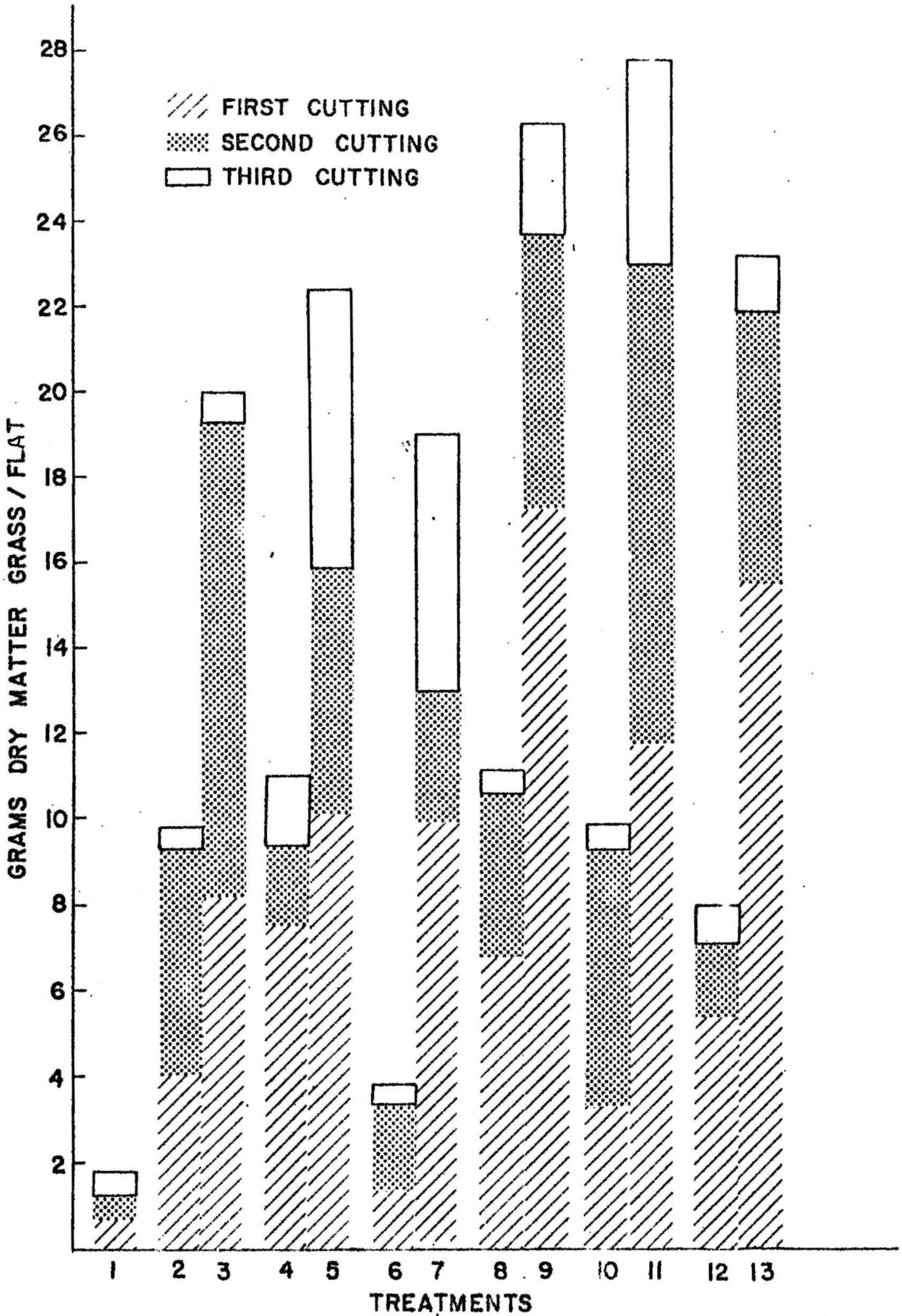

Fig. 6. Effect of various N sources, rates and cuttings on dry weight of Bermudagrass. (Refer to opposite page for description of numbered treatments).

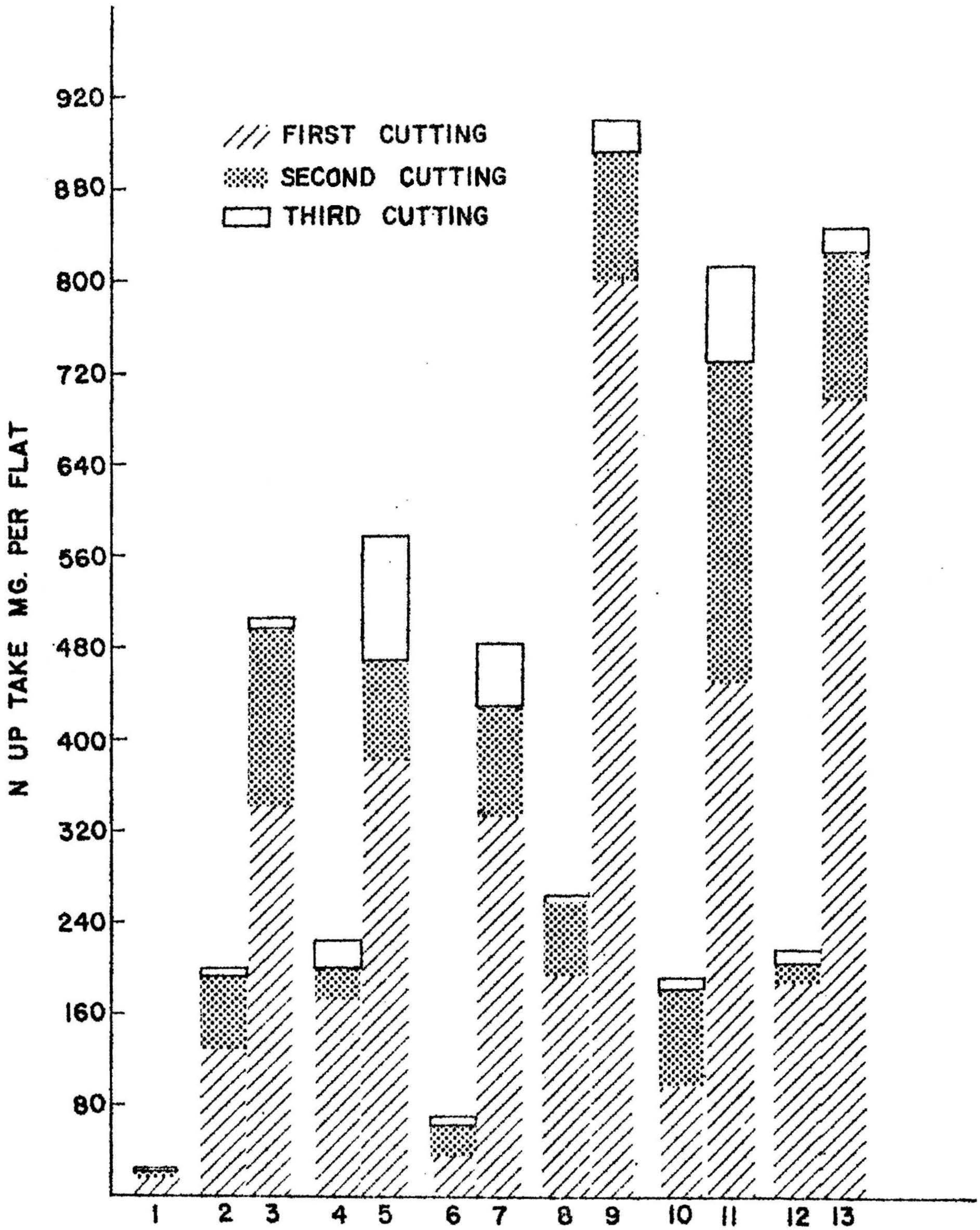

Fig. 7. Effect of various N sources, rates and cuttings on N uptake of Bermudagrass. (Refer to opposite page for description of numbered treatments.)

Treatments:

1. Control

3 and 2. $(NH_4)_2SO_4$ at 200 and 400 lb N/A rate respectively.

4 and 5. Sewage sludge at 200 and 400 lb N/A rates respectively.

6 and 7. Agriform at 200 and 400 lb N/A rates respectively.

8 and 9. Osmocote at 200 and 400 lb N/A rates respectively.

10 and 11. Sulfur-coated urea at 200 and 400 lb N/A rates respectively.

no number flat and 13. IBDU at 200 and 400 lb N/A rates respectively.

Treatments:

1. Control.

3 and 2. $(NH_4)_2SO_4$ at 200 and 400 lb N/A rates respectively.

4 and 5. Sewage sludge at 200 and 400 lb N/A rates respectively.

6 and 7. Agriform at 200 and 400 lb N/A rates respectively.

8 and 9. Osmocote at 200 and 400 lb N/A rates respectively.

10 and 11. Sulfur-coated urea at 200 and 400 lb N/A rates respectively.

12 and 13. IBDU at 200 and 400 lb N/A rates respectively.

SUMMARY

Effect of temperature on mineralization of slowly-available nitrogen fertilizers has been studied by incubating six different sources of nitrogen [$(NH_4)_2SO_4$, sewage sludge, Agriform (urea-formaldehyde compound), Osmocote, sulfur-coated urea and IBDU] in the Lualualei and Wahiawa soils at 7^{o}C., room temperature (27^{o}C.), and 40^{o}C., and analyzing the NH_4-N and NO_3-N at 0, 1, 2, 4, 8, 16, and 24 weeks. The results from the incubation study are summarized as follow:

1. Ammonification took place at all temperatures and its rate increased with increasing temperature. Accumulation of NH_4-N was higher in the Wahiawa soil than in the Lualualei. The sulfur-coated urea produced the highest amount of NH_4-N and at the most rapid rate in both soils at all temperatures.
2. Nitrification rate in the Lualualei soil was more rapid than in the Wahiawa soil at all temperatures. Nitrification in the Wahiawa soil was delayed for several weeks at 7^{o}C. and 40^{o}C. incubation. The most rapid rate of nitrification in the Wahiawa soil was at room temperature. Nitrification in the Lualualei soil increased with increasing temperature up to 40^{o}C. Osmocote produced the highest NO_3-N in both soils at all temperatures.
3. Mineralization of slowly-available nitrogen fertilizers increased with increasing temperature up to 40^{o}C. The Wahiawa accumulated more of the available nitrogen (NH_4+ NO_3) from all slowly-available nitrogen fertilizers and at all temperatures than the Lualualei soil. An exception

was with IBDU at room temperature and at 40^{o}C. incubation. At 7^{o}C. incubation the mineralization of all sources was not completed because of low ammonification and nitrification. At room temperature and 40^{o}C. incubation, mineralization of all sources proceeded rapidly because of the stimulating effect of temperature on the microbial activities and subsequent decomposition of organic nitrogen compounds and an increase in the release rate of soluble nitrogen in the coated fertilizers (sulfur-coated urea and Osmocote). Osmocote released the highest amount of available nitrogen in both soils at all temperatures, followed by sulfur-coated urea, IBDU, Agriform and sewage sludge. The most complete mineralization and the best recovery of available nitrogen was found in the Osmocote and sulfur-coated urea treatments. IBDU was considered as moderate in terms of mineralization rate and amount of available nitrogen released. The rate of mineralization of Agriform and sewage sludge was very slow as compared to the other sources. These two compounds released the loewst amounts of available nitrogen in both soils. This may be due in part to the presence of undegradable form of nitrogen in these two compounds.

Greenhouse experiments were conducted to compare effects of rate and sources of nitrogen fertilizers on sweet corn (Zea Mays var. fugosa 'H-68') and Bermudagrass (Cynodon dactylon XC. Magennisii var. 'sunturf'). Sewage sludge, Agriform Osmocote, sulfur-coated urea, IBDU and $(NH_4)_2SO_4$ were used as nitrogen sources at the rate of 200 and 400 lb N/A. Vegetative yield, % nitrogen and N uptake were measured. The results from the greenhouse experiments are summarized as follow:

A. Corn Experiment

1. All nitrogen sources at the two rates resulted in higher yield of corn than the control. The yields obtained from the 400 lb N/A rate were higher than those from the 200 lb N/A rate. There was no difference in yield of corn among the various treatments at the 200 lb N/A rate. At the 400 lb N/A rate, $(NH_4)_2SO_4$, IBDU and Agriform resulted in higher yields than Osmocote, sulfur-coated urea and sewage sludge.
2. There was no difference in tissue percent nitrogen among the various fertilizer treatments but increase in nitrogen rate resulted in higher percent nitrogen of corn.
3. Total N uptake by corn increased with an application of N fertilizers and also with higher rate of application. Osmocote was the most effective fertilizer in increasing N uptake in corn, followed by IBDU. Agriform, sulfur-coated urea and sewage sludge were as effective as $(NH_4)_2 SO_4$ in this respect.

B. Grass Experiment

1. Vegetative yield of grass increased with application of nitrogen fertilizers and with higher rate of N applied. Yields obtained in the first cutting were highest, followed by those in the second and third cuttings. At first cutting, the highest yield of grass was obtained from Osmocote, followed by IBDU, sewage sludge, sulfur-coated urea $(NH_4)_2SO_4$ and Agriform. At the second cutting, where yields were generally lower than at the first cutting, only $(NH_4)_2SO_4$ and sulfur-coated urea gave higher yields than at the first cutting. At the third cutting, $(NH_4)_2SO_4$ did not increase yield over that of the control, but the slowly-available nitrogen fertilizers were still able to produce some yields. The highest yield in the third cutting was obtained from sewage sludge, followed by sulfur-coated urea, Agriform, Osmocote and IBDU. The following order of total yield of three cuttings was as follows:

   Osmocote = sulfur-coated urea>sewage sludge> IBDU = $(NH_4)_2SO_4$>Agriform.

2. The percent nitrogen in grass was highest in the first cutting and then decreased in the subsequent cuttings. The percent tissue nitrogen of grass increased with an increase in the rate of nitrogen

application. The effectiveness of nitrogen fertilizers in increasing % nitrogen in grass was found to be in this order:

Osmocote = sulfur-coated urea = IBDU> $(NH_4)_2SO_4$ = sewage sludge and Agriform.

3. The most effective N sources in producing the highest total N uptake were Osmocote, sulfur-coated urea and IBDU, followed by sewage sludge. Agriform produced the lowest N uptake but this was not significantly different from that of $(NH_4)_2SO_4$.

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